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16. ABSTRACT

This report was prepared to guide persons responsible for disposing of oil spill debris in selecting suitable methods and sites, and in carrying out effective, environmentally safe disposal operations.

Volume I is a procedures manual useful both in office and field. Topics covered include site selection and preparation, method selection, implementation of three alternative disposal methods, site monitoring requirements, and correctional measures for possible environmental problems. All available land disposal methods (other than systems employing incineration) were investigated prior to selecting the three recommended alternatives: land cultivation (also called landspreading), burial, and sanitary landfilling. An outline for a training course on oil spill debris disposal is also included.

Volume II presents a bibliography and a summary of the current literature relating to oily waste decomposition, migration through soils, and interaction with the environment. Calculations are provided to indicate the theoretical limitations on degradation. Case studies of two sites where the land cultivation disposal method was used to aerobically decompose the oily debris, and at two other sites where the debris was buried in specially constructed cells, are described and the effectiveness of each operation is evaluated.

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OIL SPILL: DECISIONS FOR DEBRIS DISPOSAL

VOLUME II

LITERATURE REVIEW
AND
CASE STUDY REPORTS

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL - Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This two part report comprises both a user's manual for oil spill debris land disposal by land cultivation, sanitary landfilling, or burial, and a technical backup manual which includes the results of a literature search and four case studies. The report is intended to provide both the directions for oil spill debris disposal and the rationale behind them. Oil spill On-Scene Coordinators and local officials should find this report directly applicable for prior planning and during spill cleanup operations. For further information, please contact the Oil & Hazardous Spills Branch of the Resource Extraction & Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

This report was prepared to guide persons responsible for disposing of oil spill cleanup debris in selecting suitable sites for debris deposition and in effecting proper disposal operations. A literature search and four case study investigations were conducted to verify the practicality and environmental acceptability of each disposal method described.

Project results are presented in two volumes and an introductory film.

The "Procedures Manual" (Volume I) is designed to be useful as both an office and field guidebook. Land disposal topics covered include site selection, disposal method selection, implementation of three alternative disposal techniques, site monitoring procedures, and possible correctional measures for environmental problems. All available disposal methods which may be employed when incineration or other processing is impossible or impractical were investigated prior to selection of the three recommended alternatives: land cultivation, burial, and incorporation into sanitary landfills with refuse. An outline for a training course on oil spill debris disposal is included in Volume I.

A 15 minute color training film was prepared as a companion to the Procedures Manual.

Supporting technical data is presented in an Appendix volume, "Literature Review and Case Study Reports" (Volume II). Volume II contains a summary of the current literature relating to physical and chemical interaction of oil and soil, biological degradation of oil spill debris, the relationship of oily waste disposal to vegetation, and oil spill debris disposal methodologies. Calculations are provided to indicate the theoretical limitations on degradation, evaporation, and other factors to verify data reported in the literature. Disposal cost estimates are also included. A bibliography of 67 pertinent references is provided.

Volume II also contains a description of four case studies conducted at sites that have accepted oil spill cleanup debris and/or oily wastes. The land cultivation disposal method was used to aerobically degrade the oil material at two sites. Oil

spill debris was buried with soils in specially constructed cells at the other two sites. Samples of oily material, surrounding soils, and local groundwater were analyzed for various constituents to determine the extent to which the disposal activities at each site impacted the environment.

This report was submitted in satisfaction of EPA Contract Number 68-03-2200 and describes work completed from June 1975 through January 1977.

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Dr. Ronald J. Lofy reviewed much of the technical information, and Dr. Dallas Weaver contributed analytical expertise to the literature review summary. Mr. Kenneth Borgers developed the film script and monitored all filming activities. The film was prepared by Rick Spalla Video Productions, Hollywood, CA. Clerical support was provided by Roxanne Martin, Lona Taylor, and Susan Biddle.

INTRODUCTION TO VOLUME II

Volume II includes information developed as a basis for preparation of the oil spill debris land disposal procedures manual, Volume I. This supporting information is presented in two parts:

- Part 1 - Oily Waste Disposal on Land: A Literature Review;
- Part 2 - Case Studies of Oil Spill Debris Disposal Sites.

LITERATURE REVIEW

The literature review represents state-of-the-art information available through mid-1976. Many investigations of oily waste disposal to land are currently underway, and so much more information is expected to be available in the future. For example, little is now known about the impacts of growing edible crops on oil-treated land, but some research is ongoing and more is planned. Consequently, this literature review should be viewed as a first step in compiling data relevant to oil spill debris disposal, not the final word.

CASE STUDIES

Four case study sites where oil spill debris has been deposited were investigated. Pertinent background information concerning each site was gathered and is reported here to illustrate how others dispose of oily waste. In addition, a limited analytical program was performed at each site. Test wells were drilled, and soil and oily waste samples obtained. Groundwater, soil, and oil samples were analyzed to determine some of the environmental impacts of the operations in the immediate vicinity of the disposal sites.

Results of these field studies suggest that oil migration away from a debris disposal site can occur, especially in porous soils. However, the evidence to date is insufficient to document the areal extent or environmental effects of such migration.

PART 1

OILY WASTE DISPOSAL ON LAND: SUMMARY OF LITERATURE REVIEW

BACKGROUND

In the United States alone, an estimated 76 million liters (20 million gal) of potentially dangerous materials are released annually to the environment by a reported 13,000 accidental spills. Over 60 percent of the material reported spilled is of an oily nature (36).* Much work has been devoted to developing and refining methods of removing spilled wastes from water or soil; but the ultimate problem of what to do with the resultant debris has not been resolved.

Recently, it has become obvious that past debris disposal practices may cause secondary pollution problems rivaling those of the initial spill. Thus, one objective of this project was to investigate the literature and compile information pertinent to oily waste disposal.

Literature sources contain very little information specifically related to oil spill debris or its disposal. Much of the literature information cited in this volume was developed from studies of wastes by petroleum refineries. Also, several oil industry experts on oily waste disposal were consulted and interviewed. For the purposes of this literature review, the interaction between oil and the environment is considered similar if not identical, whether the waste oil is from a refinery operation or is contained in oil spill debris.

This information provides the basis for the selection of oil spill debris disposal methods presented in Volume I of this project report. Five major topics are addressed in this review:

1. Physical Interactions of Oil and Soil: Migration and Volatilization of Oily Materials;

2. Chemical Impacts of Oily Debris Disposal;

---

*References, identified by arabic numbers and listed alphabetically, are numbered consecutively starting on page 50.

3. Biological Degradation of Oil Spill Debris;
4. Relationship of Oil Disposal to Vegetation; and
5. Disposal Methodologies.

For the purposes of this review, it is assumed that contamination of ground and surface waters by oil is to be avoided. Investigation of the specific environmental and health effects of oil contaminated waters is beyond the scope of this project.

PHYSICAL AND CHEMICAL INTERACTIONS OF OIL AND SOIL: MIGRATION AND VOLATILIZATION OF OILY MATERIALS

In dealing with the migration of oil within the soil matrix, it is necessary to recognize the role of debris. An oil spill cleanup can generate various types of debris, depending upon spill and cleanup locations, oil type, cleanup methods, and many other factors. Table 1 indicates some typical variables and lists basic characteristics which could be encountered. Considering just these variables, a huge number of different combinations of oil and debris are possible. However, for the purpose of determining oil spill debris characteristics and disposal methods (other than incineration), it is not necessary to study a multitude of combinations; only gross differences in physical conditions need be considered. A basic understanding of oil flow characteristics from debris material and through the underlying soil is particularly important so that proper disposal techniques can be used to prevent captured and disposed oil from recontaminating the environment.

Significant removal (to the atmosphere) of certain oily components can be achieved through the process of volatilization. The degree of oil loss by volatilization and subsequent movement through the soil matrix is related to the vapor pressures of the oil substances and the partial pressure of oxygen in the soil environment. (These factors also influence the rate of aerobic biological degradation of the oily wastes, as discussed later.)

Debris Characteristics

Four basic characteristics of oil spill debris influence the potential for immediate and long term oil migration from the debris mass:

- Oil content;
- Water content;
- Chemical content; and
- Biodegradability of solid debris and/or sorbents.

TABLE 1. BASIC VARIABLES IN OIL SPILL CLEANUP DEBRIS

Type of Oil	Sorbent Used	Oil Content	Water Content	Chemicals Used	Solids Entrained
1. Crude	1. None	1. High	1. High	1. Dispersants	1. Sand
2. Residual	2. Natural product	2. Low	2. Low	2. Detergents	2. Dirt
3. Distillate	3. Artificial product			3. Emulsifiers	3. Rocks
				4. None	4. Vegetation (seaweed, turtle grass, etc.)
					5. Storm debris (driftwood, etc.)
					6. Refuse

In general, the higher the oil content in collected debris, the greater the likelihood that oil would escape from the mass at the disposal site at the time of (or very soon after) deposition. Debris containing a relatively low percentage of oil would tend to retain oil on surfaces of vegetation, soil, rocks, and other debris constituents. The maximum oil sorption capacity of a number of sorbents in the presence of water has been extensively researched (53). However, the rate of oil release from sorbents under disposal site conditions has not been evaluated.

The degree of emulsification and the ratio of oil to water also determine the extent to which the oil/water mixture will flow (5, 24, 66). A highly emulsified oil/water mixture may be less likely to flow from debris and into the underlying soil than an unemulsified oil contained in spill cleanup debris.

Pore spacing within the debris particles is another factor that affects the potential for oil release. The smaller the pores (as in a silty or clayey soil collected during cleanup of an oil spill on land), the less likely that oil will migrate from the debris.

The solid fraction of oil spill debris can include various materials such as naturally-occurring solids (rocks, sand, dirt, seaweed, etc.) and added sorbent materials (straw, polymerics, etc.). The degree to which the solid portion of spill debris degrades and the corresponding rate of degradation influences the long term outward migration rates of the oil.

Biodegradable debris buried underground with or without refuse can readily degrade under anaerobic conditions. However, the oil itself will degrade very slowly in this atmosphere, requiring many decades. Debris that degrades either anaerobically underground or aerobically in a land cultivation operation will tend to release any undegraded oil which is absorbed within or absorbed onto the surface. Pore spacings between debris particles will also change during debris degradation, thus influencing oil migration.

Oil spill debris collected from a water environment may contain a water-in-oil emulsion. Typically, a water-in-oil emulsion exhibits the properties of a heavy petroleum product. Such an emulsion is a two-phase system - the continuous phase and the water held in suspension. With this combination, the viscosity of the mixture may be significantly higher than the viscosity of either constituent alone (44).

Little data exist on the range of viscosity obtained with different oil and water combinations. However, it is generally recognized that viscosity increases can be significant (25). In the Bay Marchard Fire of 1972, for example, a sample of crude taken before the fire had a viscosity of 3 centipoise at 70°F, while after the spill the emulsion was measured at 900 centipoise (47). The viscosity of a water-in-oil emulsion entrained in oil spill debris would expectedly be somewhat lower than 900 centipoise due to evaporation of both water and volatile gases from the oil.

Several formulations of chemicals are used occasionally to facilitate oil spill cleanup and to minimize further contamination. Depending on their characteristics, the chemical additives are used as dispersants, emulsifiers, detergents, and degreasers (58). In general, these chemicals act to separate the oil into miniscule particles and increase exposed surface area. The viscosity of chemically treated oils is decreased, and, thus, the potential for outward flow of oil from spill debris is increased. Oil column experiments with oil-detergent emulsions show that the oil-chemical mass can more readily percolate through porous sand than does the unemulsified oil. Oil treated with detergent has been observed dispersed throughout considerable depths of beach sand (34, 46). Normally, untreated oils do not penetrate sand beyond several centimeters. Data on viscosity properties of emulsions of oil and other types of chemicals are generally lacking. The degree to which flow is enhanced is dependent on the type of oil, the particular chemical(s) used, the relative chemical-oil concentrations, and the specific reactions occurring between the oil and chemical(s).

Soil Characteristics

Once oil has flowed from the debris mass to the underlying soil, geohydrological conditions at the land disposal site will determine the potential for further oil migration and possible environmental degradation.

Soil porosity and permeability are the two factors that most significantly affect subsurface oil flow. These factors are related according to Darcy's Law, which defines the flow of any fluid through a porous medium completely saturated with a single homogeneous fluid. Equation 1 shows this relationship (16):

$$V = \frac{Ph}{L} \qquad \text{(Eq. 1)}$$

where $V \doteq$ velocity of fluid through a column of permeable materials;

P = constant which depends on the character of the material (coefficient of permeability);

L = length of column; and

h = difference in head between the ends of the column.

However, porous media such as soil and spill debris are not always homogeneous since water and gases are also usually present to varying degrees. The classic three-phase fluid-flow pyramid depicted in Figure 1 illustrates the more typical situation encountered (66). Interactions between the three materials occur at the various interfaces and affect the respective flow rates as well as the relative permeabilities of each. The permeability rates are in turn affected by viscosity ratios, interfacial tensions, temperature, and pressure gradients.

In the case of an oily waste deposited in soil, the more volatile components may have already evaporated. The remaining water and oil then participate in a two-phase system. The various combinations between these two can be graphically portrayed, as shown on Figure 2. With such oil and water systems, a relatively high level of oil saturation is required before flow will commence (21, 35, 39, 66).

Assuming that the degree of soil saturation by oil is sufficient for flow to commence, the porosity, hydraulic gradient, and permeability of the soils are the major parameters controlling the rate and extent of subsurface migration. The porosity of a soil is an important factor in determining potential oil infiltration. At a fixed level of residual saturation, oil will flow through a particular set of pores (16). Assuming that these pores are interconnected as shown in Figure 2, there is a certain probability that a chain of pores able to pass a particular phase will exist (44).

It is difficult to precisely delineate the transition between pendular saturation (where the wetting phase is not continuous and the non-wetting is in contact with a solid surface), and funicular (where wetting phase is in contact with a solid surface).

The higher the degree of saturation, the greater the probability of interconnection. Saturation can be visualized as a function of three factors:

- The size of the entry to a pore;
- The number of pores which are occupied by the oil phase; and
- The extent to which a particular phase saturates a stratum.

The potential for movement of oil through soils is reduced with increasing soil moisture content. The movement of oil in soil, therefore, depends largely upon the degree of oil saturation, hydraulic gradient, and soil permeability (38). Oil

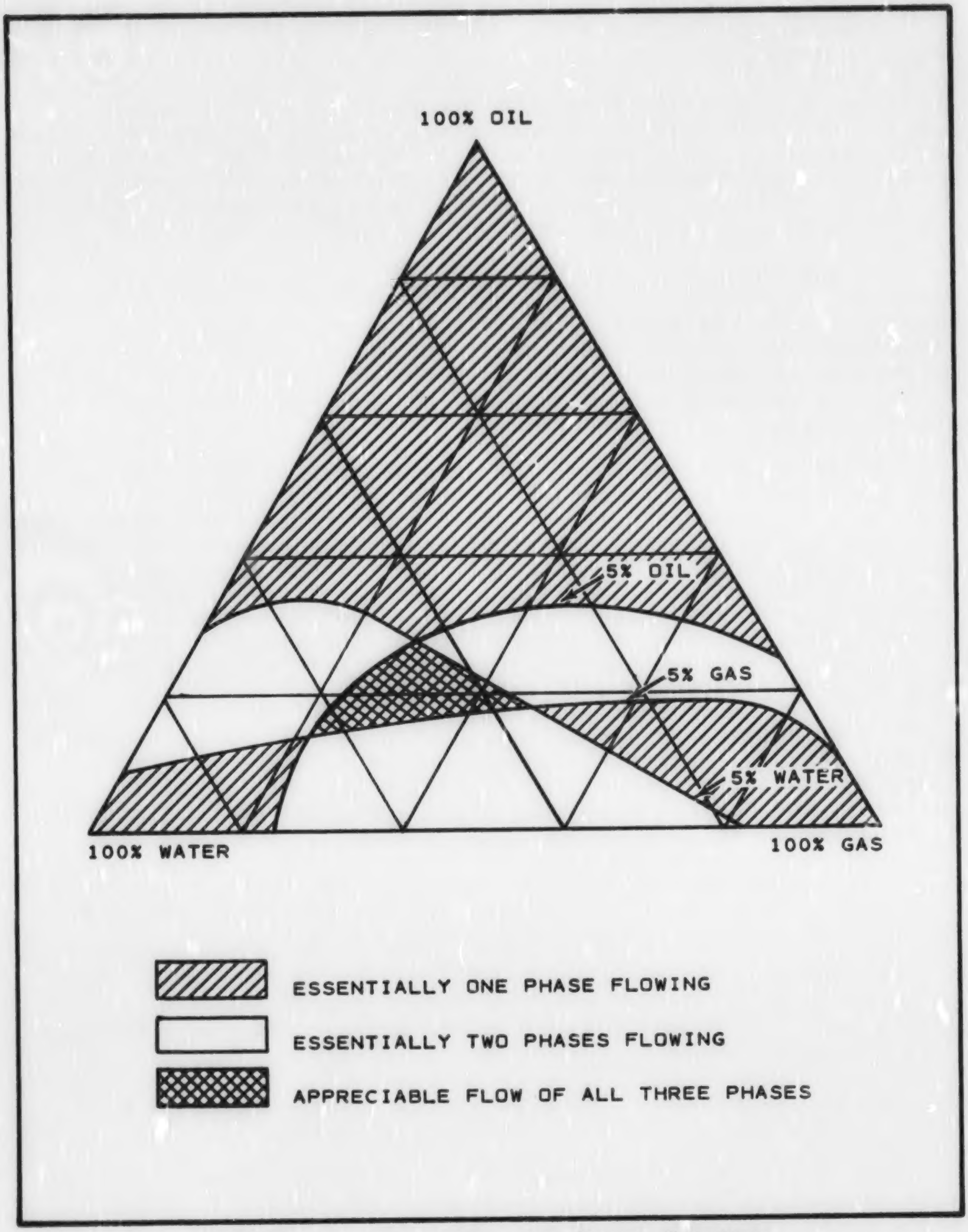

100% OIL
5% OIL
5% GAS
5% WATER
100% WATER
100% GAS
▨ ESSENTIALLY ONE PHASE FLOWING
☐ ESSENTIALLY TWO PHASES FLOWING
▩ APPRECIABLE FLOW OF ALL THREE PHASES

FIGURE 1. OIL, GAS, AND WATER PYRAMID
(AFTER WYLLIE, REF. 66).

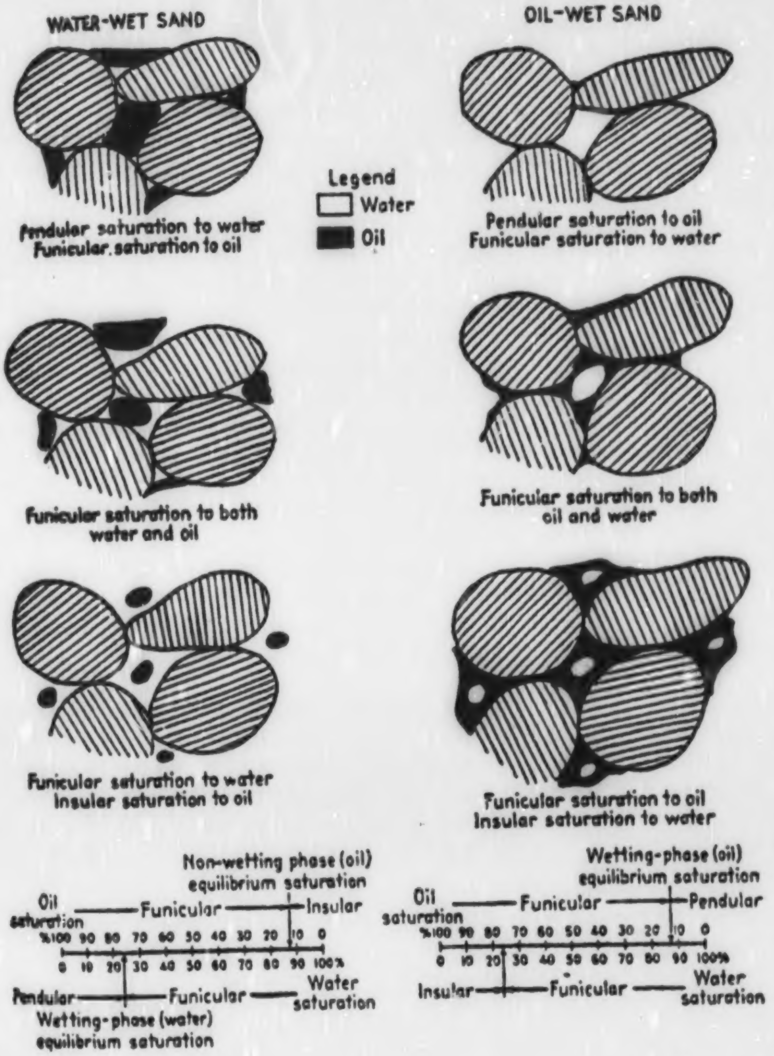

WATER-WET SAND
OIL-WET SAND
Legend
Water
Oil
Pendular saturation to water
Funicular saturation to oil
Pendular saturation to oil
Funicular saturation to water
Funicular saturation to both water and oil
Funicular saturation to both oil and water
Funicular saturation to water
Insular saturation to oil
Funicular saturation to oil
Insular saturation to water
Non-wetting phase (oil) equilibrium saturation
Oil saturation
Funicular
Insular
%100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100%
Pendular
Funicular
Water saturation
Wetting-phase (water) equilibrium saturation
Wetting-phase (oil) equilibrium saturation
Oil saturation
Funicular
Pendular
%100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100%
Insular
Funicular
Water saturation

FIGURE 2. TWO PHASE OIL AND WATER SYSTEMS (AFTER PIRSON, REF. 44).

adhering to soil grains inhibits oil movement until oil content increases to levels where a set of pores become interconnected.

"Pores facilitating oil flow are those which are larger than pores passing only water and smaller than pores passing only gas. The number of pores occupied by oil also depends upon the particle size, distribution of the soil and the degree of oil saturation," according to Pirson (44). If water content were increased and the degree of oil saturation maintained constant, the oil would be forced to occupy fewer pores of larger size than it did previously (22). Soil with a relatively high water content has been shown to retard oil infiltration from waste oil deposition sites on land.

The preferential wetting of soil particles by water will greatly influence the ability of the oil to migrate. Clayey soils, for example, tend to hinder oil flow because the pore spaces are occupied by water. Granular soils generally do not retain water as readily and thus present an easier flow path for oil (21). However, even granular soils can hinder oil flow if saturated with water. A study conducted by the U.S. Naval Civil Engineering Laboratory showed that even fine sands, when water saturated, are impervious to most oils (18). Thus, nearly all soil types if under maximum field capacity will present an effective barrier to the migration of oil. Oil infiltration into soil at a debris disposal site can be minimized by sorting and compacting the soil prior to waste deposition. However, any water soluble contaminant contained in the oil or debris may leach into the underlying saturated soil.

This behavior is also evidenced when oil seeps into the ground to a point near an aquifer. In the capillary zone immediately above the water table, the water content begins to increase, reaching 100 percent at the water table. In very fine-grained sediments, the capillary zone may be 0.38 to 0.46 m (15 to 18 in) thick; in coarser-grained material, 2.5 to 7.6 cm (1 to 3 in) is common.

Migration of Oil through Soil

The expected extent of oil migration from spill debris through underlying soils and the oil transport rate are influenced by site-specific characteristics of the oil and underlying soil. The complex interactions of these variables create a situation where quantitative oil migration predictions are nearly impossible. However, information is available to enable an approximation of the total volume of soil required to immobilize a given mass of oil. Equation 2 shows the relationship (16):

$$\text{Volume of soil required to attain immobile saturation (volume in cu yd)} = \frac{0.20 \times V}{P \times S_r} \qquad \text{(Eq. 2)}$$

where: V = volume of oil in barrels

P = porosity of soil

S_r = residual saturation

Typical values of residual saturation (S_r) are shown below (14):

Oil Type	S_r
Light oil and gasoline	0.10
Diesel, light fuel oil	0.15
Lube and heavy fuel oil	0.20

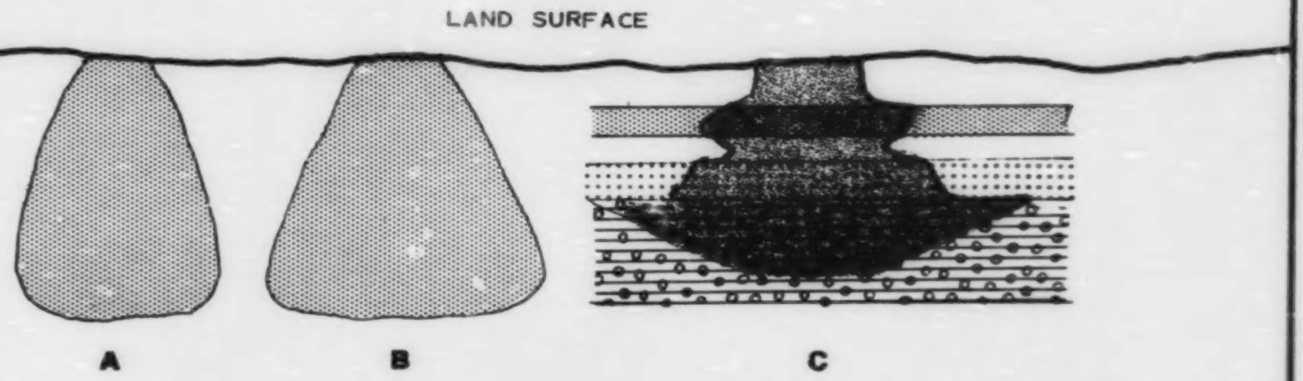
Equation 2 suggests that soils of high porosity can best impede both vertical and lateral oil migration away from the disposal area. It is difficult to precisely portray oil pathways due to the multi-faceted variables possible. A generalized cross-section consists of vertical movement under the force of gravity with some degree of lateral dispersion depending upon soil homogeneity. Figure 3 depicts some qualitative oil migration patterns possible through different soil types.

As the descending body of oil reaches the top of the capillary zone, the oil begins to spread over the water table. It spreads in a layer, roughly the thickness of the capillary zone, and elongates in the direction of the water's movement. The oil continues to move, forming a pancake-shaped layer, until it reaches immobile saturation or returns to the surface at a discharge point (16).

Vertical oil movement will eventually be interrupted for one of three reasons: (1) the oil will spread until immobilized by soil absorption; (2) it will encounter an impermeable bed of soil; or (3) it will reach the groundwater table. An idealized cross-section of this movement is shown on Figure 4.

Most oil that contacts groundwater will float near the water surface though some of the lighter oil fractions may diffuse into the water (22). Floating oil tends to move with the water and is absorbed continually by soil particles which it contacts. This soil filtering process will eventually remove the entire non-soluble oil fraction.

Water contaminated by the soluble oil fraction can theoretically move significant distances down-gradient depending on characteristics of the aquifer, the amount of oil being leached, and the threshold of analytical capability. However, available records of case histories indicate that actual migration is minimal. For example, in a land cultivation operation in Marcus Hook, Pennsylvania (50), 66.8 m^3 per ha (170 bbls/acre) of crude



GENERALIZED SHAPES OF SPREADING CONES AT IMMOBILE SATURATION

A - HIGHLY PERMEABLE, HOMOGENEOUS SOIL
B - LESS PERMEABLE, HOMOGENEOUS SOIL
C - STRATIFIED SOIL WITH VARYING PERMEABILITY

FIGURE 3. GENERALIZED EFFECTS OF SOIL CHARACTERISTICS UPON OIL FLOW (AFTER DAVIS. REF. 16.

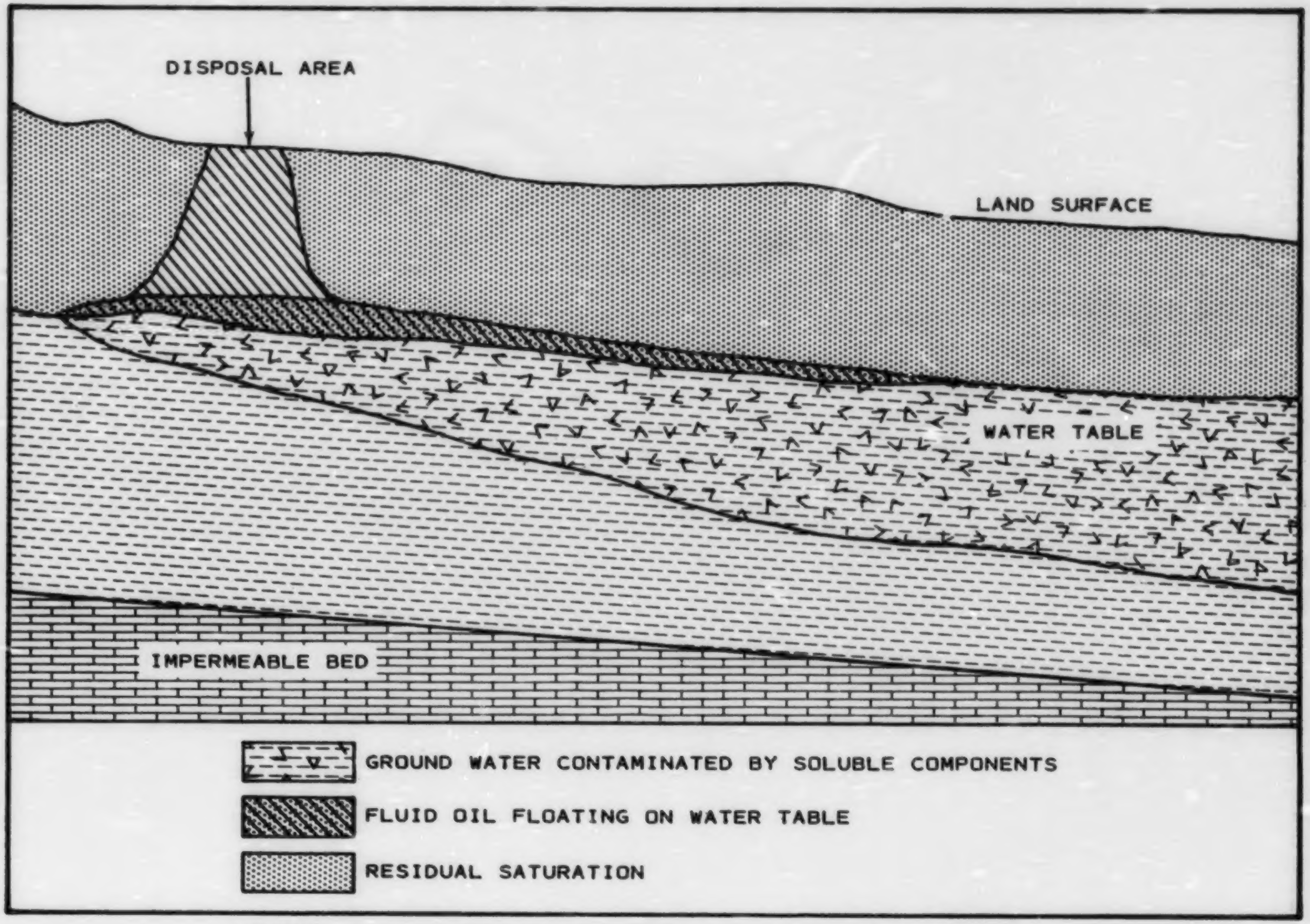

DISPOSAL AREA
LAND SURFACE
WATER TABLE
IMPERMEABLE BED
GROUND WATER CONTAMINATED BY SOLUBLE COMPONENTS
FLUID OIL FLOATING ON WATER TABLE
RESIDUAL SATURATION

FIGURE 4. ILLUSTRATION OF IDEALIZED SUBSURFACE OIL FLOW (AFTER DAVIS, REF. 16).

oil were rototilled into the ground to a depth of 15 cm (6 in). After one year, corings indicated that the oil had migrated only 0.3 cm (1/8 in). Like the Marcus Hook investigation, other studies representing widely divergent oil types, geohydrologic conditions, and disposal methods, have indicated that the distance of subsurface migration of bulk oil is small.

Potential Impacts of Oily Waste Disposal on Water Quality

Leaching of oily wastes into groundwater can generate serious pollution problems. Oils in groundwater can contaminate water wells or may be transported to surface waters where they may pose difficulties for conventional water treatment plants. Even the most permissive water quality criteria state that oil should be entirely absent from public supplies. Furthermore, oil from oil spill debris can contain many contaminants, including heavy metals and other ions. Upon degradation, the organic acids and decomposition gases may leach salts present in the soil and thus cause additional groundwater contamination.

The amount of metallic and other elemental and chemical contaminants in oils depends upon the source of the oil. The range of concentrations can be from virtually zero to fractional percentage ranges (3,000 ppm). For example, crude oils of Venezuelan origin contain high concentrations of vanadium while waste motor oils can contain significant amounts of lead. Oil spill debris comprised of oils with high metals concentration could be a local source of environmental contamination if improperly disposed of on land, particularly if the site overlies usable groundwater.

Insufficient information is available to enable the prediction of environmental contamination from oils disposed of on land. Chemical contamination from improperly situated debris disposal sites may be a major threat, since several heavy metals have been shown to be relatively immobile in various soils. On the other hand, studies of sewage sludge disposal on land have indicated lead may be a very mobile metal in soils (56). A potential problem could occur from continuous use of a particular site for disposal of a high metals content oil, such as used motor oil. Such a site would likely become indefinitely unusable for other purposes such as residential development or production of edible crops unless covered with several meters of uncontaminated soils at the conclusion of disposal operations.

Evaporation of Oil During Land Application

Oily materials can migrate from the land disposal site by subsurface migration, surface runoff, and volatilization. The potential for oil loss from a debris disposal site depends mostly on the types of hydrocarbons in the debris. Clearly, high vapor pressure hydrocarbons such as propane will vaporize before any significant degree of outward migration or biological oxidation can occur in soils. However, lower vapor pressure hydrocarbons such as heavy oil, residual fuel oils, grease, solid paraffins, and high molecular weight asphaltenes may migrate or be biologically oxidized before they are ever evaporated.

In order for a component of a hydrocarbon contained in a soil or debris to evaporate and be transported to the atmosphere, it must have a pathway available. This pathway would also allow atmospheric oxygen to reach the oil surface; hence, local aerobic conditions must exist. If the required moisture, nutrients, and microbiological species also exist at this aerobic interface, biological decomposition can readily occur as the microorganisms utilize the free energy available in the oxidation of the hydrocarbons. Thus, in considering the potential for evaporation of oil from a debris disposal site, the relative rates of biological oxidation and evaporation must be considered.

Experimental evidence shows the range of time constants relevant to biological oxidations. The actual biological time constants depend upon the specific hydrocarbons, oxygen and water partial pressures, temperature, biological species and genetics, along with nutrient availability. The range of values is generally between two and 20 months under reasonable, controlled aeration and moisture conditions.

One can compare these approximate time values with expected evaporation rates of hydrocarbons through soils. The rate of evaporation depends upon the vapor pressure of the hydrocarbon, soil porosity, tortuosity, and surface absorption characteristics of the soil. The following derivations have been compiled from various sources (6, 15, 31, 64). The mass transport can be described by:

$$\frac{dC}{dt} = \nabla \cdot D_{eff} \nabla C \qquad \text{(Eq. 3)}$$

where C = oil concentration

D_{eff} = effective diffusion coefficient

$\nabla\cdot$ = divergence operator

∇ = gradient operator

t = time

The effective diffusion coefficient would include the various soil parameters mentioned above. If it is assumed that surface absorption does not change with time (i.e., the surfaces do not absorb the hydrocarbon), the effective diffusion rate can be approximated as:

$$D_{eff} = \frac{D_o \alpha}{\tau} \qquad \text{(Eq. 4)}$$

where D_o = intrinsic diffusion rate of the hydrocarbon

α = void fraction

τ = tortuosity

The boundary conditions for a one-dimensional soil column can be approximated by assuming the concentration of oil is zero at the surface of the soil and proportional to the vapor pressure of the hydrocarbon at a distance x_1 below the surface. For this case, we are considering a problem as shown in Figure 5. In the vertical distance x_1 deep into the soil all the oil was evaporated, but a fresh supply exists for all $x \geq x_1$. Or, in other words, the boundary conditions are:

$C = 0$ at $x = 0$

$C = C_o$ at $x \geq x_1$

The flow rate through the surface, under these boundary conditions would be:

$$J = D_{eff} \frac{C_o}{x} = D_o \frac{\alpha}{\tau} \frac{C_o}{x} \qquad \text{(Eq. 5)}$$

The value of x will be increasing slowly with time. This rate of increase will depend on the amount of free oil in the soil. Using units for J of g/cm^2 sec and for C_o of g/cm^3 (vapor density) and calling β (in units of g/cm^3) the initial oil content of the soil, the distance x can be described as:

$$\beta x = \int_0^t J \, dt = D_o \frac{\alpha}{\tau} \frac{C_o}{x} t \qquad \text{(Eq. 6)}$$

$$\text{or } x = \left(\frac{D_o \alpha C_o t}{\beta \tau}\right)^{\frac{1}{2}} \qquad \text{(Eq. 7)}$$

Substituting the following typical values for a silty sand with a 10 percent initial oil content:

$D_o = 0.1 \ cm^2/sec$

$\alpha = 0.25$

$\tau = 3$

$\beta = 0.1 \ g/cm^3$

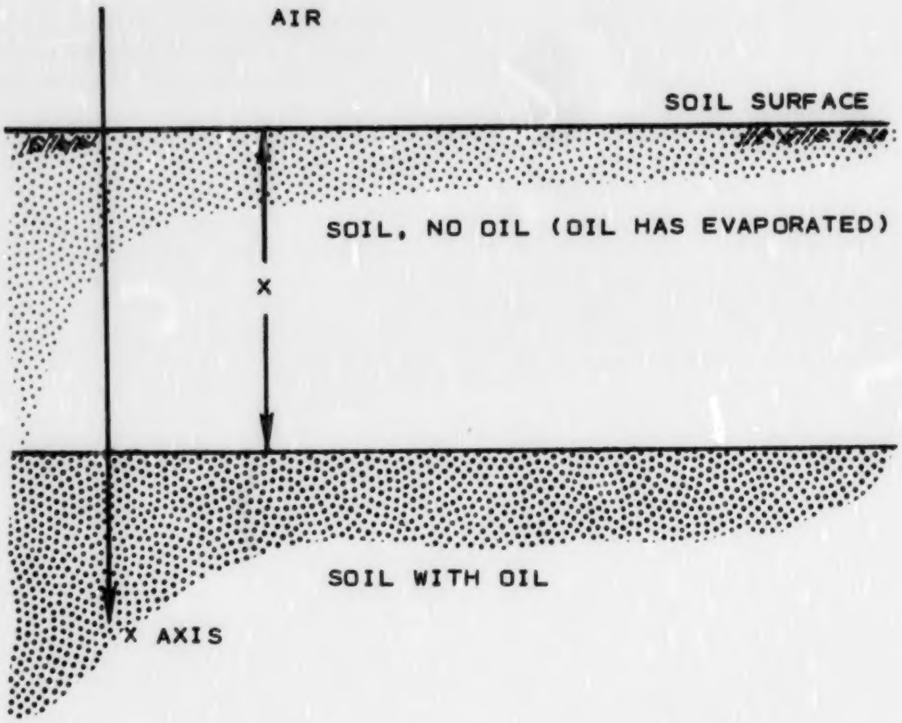

AIR
SOIL SURFACE
SOIL, NO OIL (OIL HAS EVAPORATED)
X
SOIL WITH OIL
X AXIS

FIGURE 5. ONE-DIMENSIONAL SOIL COLUMN.

and a value for C_0 of 1×10^{-4} g/cc (characteristic of a very highly volatile hydrocarbon like gasoline), it can be found that:

$$x = 2.80 \times 10^{-3} \sqrt{t} \text{ cm}$$

$$\text{for } t = 1 \text{ mo} = 2.6 \times 10^{6} \text{ sec}$$

$$x = 4.6 \text{ cm}$$

Therefore, even for a highly volatile hydrocarbon deposited in a soil to a concentration of 0.1 g/cm^3 approximately one month would transpire before all oil in the top 4.6 cm layer would evaporate.

Assuming a heavier fuel oil material with a vapor pressure corresponding to a saturated vapor phase concentration in the 10^{-6} g/cm^3 range, it can be found that $x = 0.46$ cm in one month or approximately 1.6 cm in a year. If it is assumed that the initial layer of contaminated oil is 25 cm deep, approximately 6 percent of the oil could be evaporated in two years. Hence, relative to the time constants associated with the biological decomposition, the evaporation rate is low.

Heavy oils and oil products have even lower vapor pressures or vapor phase concentrations. For example, oil used in diffusion pumps has a vapor phase composition in the 10^{-12} to 10^{-15} g/cm^3 range. Using this range of values, Equation 7 indicates that oil evaporation is insignificant.

At least one interesting conclusion can be drawn from the above analysis. The relative amounts of evaporated versus biologically oxidized oil can be affected by the disposal techniques employed. Considering the diffusion of oxygen, it becomes clear that for any hydrocarbon with a vapor pressure less than approximately 100 mm of Hg, the minimum ratio of evaporation to biological oxidation can be achieved by maximizing the depth of the plowed or mixed soil/oil layer as long as the soil is not completely saturated with water. Theoretically, replowing such a mixture of oil and sandy soil would be unnecessary until the oxidation of oil is complete. This procedure will result in lower biological oxidation rates, but will decrease the evaporation rate even more. For example, if the plowed layer thickness were doubled with the same amount of oil/cm^2 the oil concentration per unit volume would be decreased by a factor of 2. For the same time period, this would mean x would increase by $\sqrt{2}$ or that the total amount evaporated (βx) would be reduced by $\frac{\sqrt{2}}{2} = \sim 0.7$. The diffusion rate in the vapor phase of oxygen is the same order of magnitude (slightly higher) as that of hydrocarbons. The C_0 term appropriate for oxygen transfer to the oxidation front (assuming the biological oxidation is oxygen limited) is in the range of 3×10^{-4} g/cm^3.

Consequently, it can be concluded that the percent of oil evaporated would be minimized by allowing conditions to develop where the biological oxidation rate was limited by the diffusion of oxygen from the surface.

Under oxygen mass transport limiting conditions, the ratio of the amount of oil evaporated to the amount of biologically oxidized oil can be approximated as:

$$R = \frac{Q\ evap}{Q_{O2}} \times 3.4 \qquad \text{(Eq. 8)}$$

$$\approx 3.4 \left(\frac{C_o\ D_{oil}}{3 \times 10^{-4}\ D_{O2}}\right)^{\frac{1}{2}}$$

which correcting for the relative diffusion rates for oil and oxygen can be approximated as:

$$R \approx \left(\frac{C_o}{3 \times 10^{-4}}\right)^{\frac{1}{2}} \qquad \text{(Eq. 9)}$$

where C_o = vapor phase density of the oil in (g/cm^3)

$$\rho 0 = \frac{(M.W.)}{22{,}400}$$

where $\rho 0$ = vapor pressure in atmosphere and

where M.W. = molecular weight

It should be noted that these criteria would contradict those required to minimize potential groundwater contamination. One general criterion which would be valid for both situations would be to refrain from plowing when measurements indicate that a reasonable oxygen partial pressure exists in the soils (say about 2 percent oxygen). In general, coarse-grained soils will require less periodic plowing than fine-grained soils, not only because void fractions are less but because water drains less rapidly from the surface layers, impeding oxygen diffusion into the oil.

Fate of Evaporated Oil in the Atmosphere

Because disposal of oil spill debris on land may involve handling, mixing, and discing, evaporation of collected oils could be increased. Once the hydrocarbon vapor from a debris disposal site enters the atmosphere, its exact fate and its rate of reaction depends on its particular characteristics. Ultimately, all evaporated oil in the atmosphere is oxidized. The saturated, straight chain hydrocarbons are relatively unreactive in photochemical reactions, and so remain in the air for long periods. Many of the aromatics are very reactive in photochemical reactions involving ozone, NO_x, and ultraviolet light. Reaction products are typical of normal photochemical smog-forming reactions.

Very little air pollution from oil evaporation would be expected from oil spill debris disposal operations. A large (24,000 gal or 91 m^3) oil spill would increase the total hydrocarbon air pollution in Los Angeles by only 0.01 percent over a 100-day period, based on 1973 emission rates and a 6 percent evaporation rate from a land cultivation disposal site.

BIOLOGICAL DEGRADATION OF OIL SPILL DEBRIS

Oil is an organic substance and as such is subject to microbial degradation under favorable conditions. The most rapid oxidation of oily substrates occurs under aerobic conditions. Hydrocarbons may degrade only slightly if at all in an anaerobic environment (20). The fact that many pools of oil are still present beneath the earth's surface attests to the long term stability of oil in the absence of oxygen.

Under aerobic conditions, oil biodegradation is the result of microbiological attack in the soil regimen. Although the quantity and kinds of microorganisms present in soils vary with location, most soils contain millions or billions of microbes per gram. Some lack indigenous oil-utilizing microorganisms (29). But most researchers agree that bacteria and fungi possessing the ability to metabolize hydrocarbons are widely distributed in nature. In the soil, these microbes will be most numerous near the surface where oxygen, moisture, and food sources are readily available.

Many studies list more than 100 species and 30 genera of bacteria, actinomycetes, and fungi that can metabolize one or more fractions of crude oil. It has been reported that 66 percent of the hydrocarbon oxidizers found in ordinary soils were Pseudomonas species (8). Pseudomonas can grow under a wide range of conditions and with very little food. Bacteria outnumber fungi in most soils by a large margin. Also, bacteria reproduce more rapidly, so it is likely that bacteria are responsible for most of the decomposition of hydrocarbons in soils (20). This is further demonstrated by the increase in numbers of hydrocarbon-degrading soil bacteria after application of oil (43). However, enrichment effects caused by the oil-stressed conditions can kill off certain species of microbes and favor others. Studies have shown that after decomposition is completed the soil returns to a microbial equilibrium close to that of pre-oil addition levels (55).

Although the degradation process involves a multitude of microbes and environmental parameters, Equation 10 describes in general the degradation process:

$$C_xH_y + O_2 \xrightarrow[\text{nutrients}]{\text{microbes}} \text{Heat} + H_2O + CO_2 + \text{cellular biomass} \qquad \text{(Eq. 10)}$$

Thus, for maximum degradation to occur, a suitable combination of nutrients and microbes must be present in the debris itself or in the soil. Repeated application of oily materials to soil will promote and sustain oil-decomposing strains. However, in such a carbon-rich environment, lack of nutrients such as phosphorus and nitrogen may limit microbial growth (29). There are also a variety of other environmental conditions which affect degradation of oily materials in the soil including moisture, oil surface area, concentration, oxygen, temperature, pH, and the presence of organic matter. The relationships of these factors to oil degradation in soil are discussed below.

Nutrients

The types and quantities of nutrients present at an oil disposal site on land are of extreme importance. The capacity of microorganisms to grow in a given habitat is governed by the organisms' ability to utilize available nutrients. Aerobic bacteria require various types of nutrients and minerals including compounds of nitrogen and phosphorus and trace amounts of potassium, calcium, sulfur, magnesium, iron, and manganese. Studies have shown that ammonium phosphate is especially important in the microbial growth of favorable cultures (3, 14, 62).

The lack or absence of both nitrogen and phosphorus is especially significant as it will retard the natural decomposition process, resulting in a slower microbiological degradation of oily waste (60). The degree to which these nutrients improve decomposition has not been thoroughly quantified. Fertilizer has been frequently applied to compensate for these deficiencies although studies indicate that this has little effect until about 50 percent of the oil has been degraded (29, 49).

The amount of fertilizer (nitrogen and phosphorus) required to degrade a given volume of soil is not yet thoroughly understood. Experimental data from fertilizer (urea-phosphate) amended plots show an accelerated decomposition of oil. Amending the soil improves its nutritional status and encourages the rapid increase of oil-utilizing bacteria. This increase in numbers is accompanied by a decrease in the amount of the saturate fraction present in the recovered oil (14, 65). Over-fertilization should be avoided since it can result in nitrate and salt contamination of drainage water (14).

Debris materials mixed with the oil can also affect the bacterial population. In fact, the nature of oil spill debris may be inherently detrimental to decomposition of the entrained oil. For example, straw in debris has a relatively high nitrogen demand during degradation. Decomposition of the straw can thus retard the degradation of oil by robbing nitrogen from the biologically mediated process.

Moisture

Moisture is a universal transport medium for all biological processes (34). Water is needed to transport nutritional and energy substrates and metabolic waste products in and out of the cell. Thus, some moisture must be present in the debris or the soil at the disposal site if oil biodegradation is to occur. On the other hand, too much moisture in the debris-soil matrix can impede aeration and thus limit aerobic microbial activity (17). Figure 6 illustrates how the rate of oil decomposition (commonly expressed as the rate of CO_2 evolved) is affected by different soil-water conditions. Note that very moist soil impedes degradation. The different curves in each set are for various oil to soil ratios.

The optimum ratio of moisture to oil to encourage decomposition is primarily a function of soil type, debris characteristics, and climatic conditions. Available information indicates that a 20 percent water content would provide sufficient moisture to enhance oil degradation in spill debris (17).

Oil Surface Area

Since microbial activity takes place at the water/soil/oil interface, the oil surface area exposed to microbial activity will affect its rate of oxidation (33, 41). The greater the area of oil/soil/water interface, the faster the microbial decomposition rates, assuming favorable mineral, nutritional, and temperature conditions exist.

This interfacial relationship is especially pronounced where oil contacts a groundwater table. Microbial degradation will occur very slowly where oil spreads above a water table. With increasing water saturation of soil, the interstitial space between the oil/soil and oil/water decreases. This reduction limits the accessibility of bacteria to oil. Oil in contact with groundwater will eventually degrade as it spreads over the aquifer, since more interfacial area for microbial access is provided.

Some hydrocarbons, such as the heavier oils, tend to be resistent to decomposition because a relatively low surface area is usually exposed to microbial attack (17).

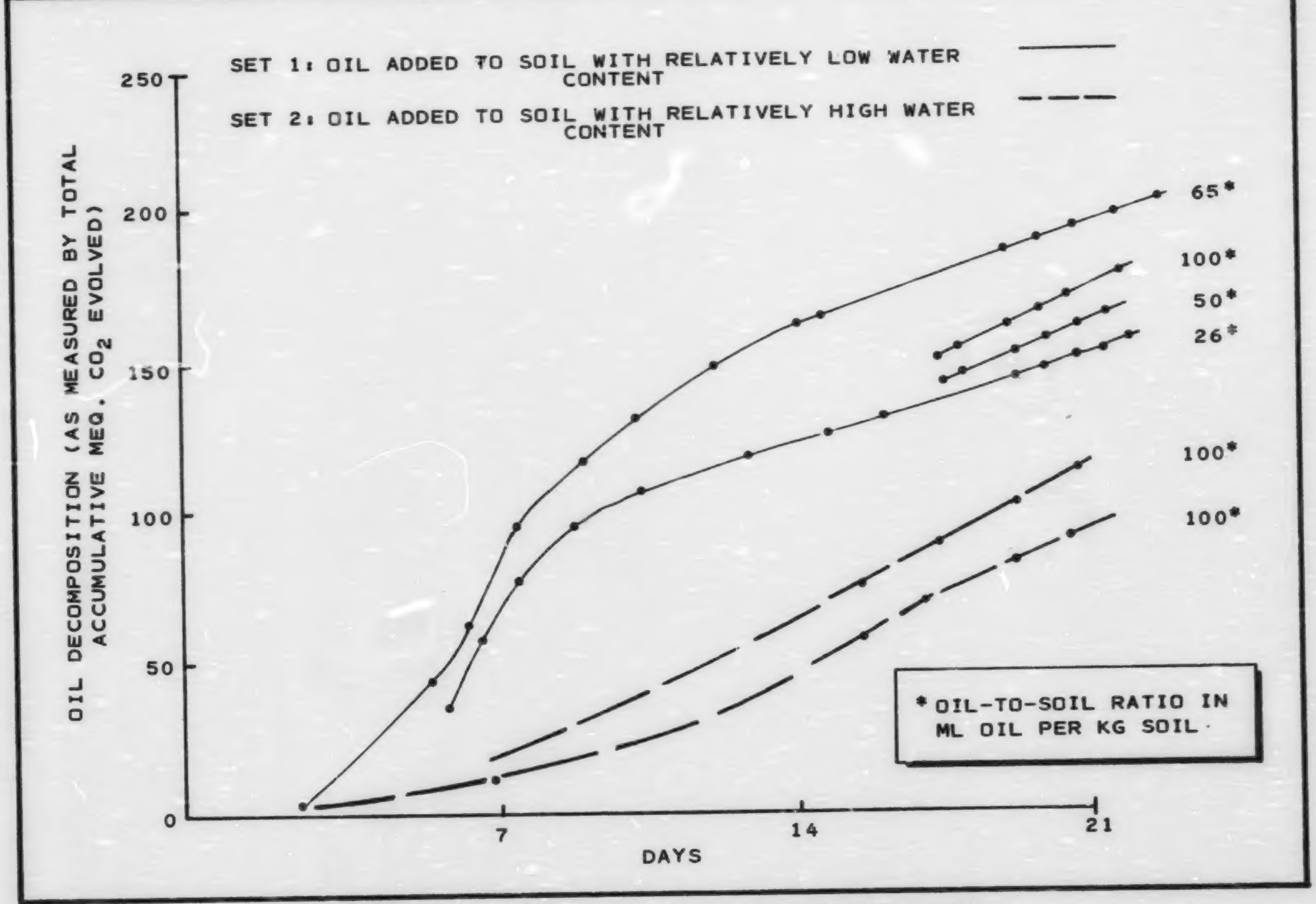


FIGURE 6. EFFECT OF WATER ON DECOMPOSITION (AFTER RAYMOND, REF. 49).

Soil microorganisms may also influence the surface area of oils through the production of emulsifying compounds (25). Such biological emulsifiers can increase the water solubility of the hydrocarbons and make them more susceptible to leaching and groundwater transport. Chemical detergents and emulsifiers have been applied to oil spills to aid in cleanup. The presence of such chemicals in spill debris tends to reduce oil surface tensions and may subsequently hinder biodegradation. Also, some detergents are fatal to microbial species that degrade hydrocarbons.

Oxygen

Oxygen is required for the rapid degradation of oils since most microbes that utilize hydrocarbons as an energy source are aerobic (42). It is generally agreed that a minimum of 3 to 4 mg of oxygen per mg of oil are required to completely oxidize the oil into carbon dioxide and water (42). This relatively high oxygen demand is due to the fact that oil has a high carbon and hydrogen content but is very low in oxygen. Thus, to encourage oil degradation, the material must be continuously exposed to an oxygen source.

The oxidizing materials can be atmospheric oxygen, sulfate, sulfite, nitrate, nitrite, or other compounds which provide net free energy for supporting life forms when combined with the oil or substrate material (11, 67). Atmospheric oxygen provides the best source for the most rapid degradation. In comparison, the reaction kinetics of sulfate-reducing bacteria utilizing SO_4 = and oil as an energy source are approximately one order of magnitude slower than aerobic bacteria using atmospheric oxygen (2, 4). Also, sulfate reaction products include hydrogen sulfide, a noxious gas that may be toxic to the oil-degrading bacteria.

To promote the transfer of oxygen to waste oil in a land disposal site, the land cultivation technique has evolved. The procedures are applicable to certain types of oil spill debris, as discussed in Section 4. As noted in Section 1, land cultivation by the periodic mixing of waste oil with surface soil will increase oil degradation rates but will promote oil volatilization.

An alternative method of increasing oxygen transport to waste oil in land disposal sites has been suggested: pumping oxygen to the soil/oil mass through a system of buried pipes. Forced convection via pipelines could be desirable where very high rates of oxygen transfer to the oil is required and when increased oil vaporization is not a problem. If relatively low rates are required, transfer by natural diffusion would provide sufficient oxygen.

An estimate of the oxygen requirements can be made as follows:

Assume:

- Initial oil/soil mixture is 25 cm thick;
- Initial oil content is 0.1 g/cm^3;
- The molecular formula for the oil is (CH_2);
- The oxidation is complete;
- Soil biomass does not change with time or is much less than 0.1 g/cm^3; and
- 300 days are required for complete oxidation.

Therefore:

- The oxygen requirements are described by

$$CH_2 + 3/2\ O_2 \rightarrow CO_2 + H_2O \qquad \text{(Eq. 11)}$$

or

3.43 g of O_2/g of hydrocarbon

- The total oil content is 2.5 g/cm^2

Therefore:

- The O_2 mass transfer rate must be greater than or equal to 3.3×10^{-7} g/sec cm^2

A lower bound on the diffusive mass transfer per unit area can be estimated by:

$$Q = D_{eff} \frac{dc}{dz} = D_o \frac{\alpha}{\tau} \frac{dc}{dz} \qquad \text{(Eq. 12)}$$

Where Q = mass flow rate in g/cm^2 sec

D_{eff} = effective diffusion coefficient for O_2 in soil

D_o = diffusion coefficient of O_2 in (N_2 + 20% CO_2) = 0.18

α = porosity ≈ 0.25

τ = tortuosity ≈ 3

$\frac{dc}{dz}$ = gradient of oxygen concentration

If it is assumed that oxygen partial pressure is near zero where the biological oxidation is occurring, the term $\frac{dc}{dz}$ can be described as $\frac{dc}{dz} \approx \frac{C_o}{\Delta z}$. (Eq. 13)

Where C_o = O_2 concentration in air = 3×10^{-4} g/cm^3

Therefore:

$$Q = \frac{4.5 \times 10^{-6}}{z} \text{ g/cm}^2 \text{ sec}$$

Assuming that the average distance required for oxygen diffusion before it is biologically reacted is on the order of 10 cm (to partially compensate for the rough open surface of a plowed field); then

$$Q = 4.5 \times 10^{-7} \text{ g/cm}^2 \text{ sec}$$

This calculated mass transfer rate for oxygen diffusion is sufficient to satisfy the biological requirements. Hence, it can be concluded that diffusive mass transfer is sufficient to decompose land disposed oil within 300 days and under the other assumed conditions. If biological oxidation within a shorter time period is required, forced convection would be necessary to achieve oxygen transport.

Temperature

Microbial growth can proceed under a wide range of temperatures, although most species attacking oil are active in the mesothermic range of 20° to 35°C (29). Each type of the hundreds of various microorganisms that interact to degrade oil are most active in specific temperature ranges. In general, it is agreed that oxidation is faster in warm or hot climates than it is in colder areas. Temperature also determines to a certain extent the types of microbial species present (62, 65). Dry, warm soils, for example, are characterized by a larger number of actinomycetes, while wetter soils do not display this abundance.

The effectiveness of bacterial species to degrade oil at different temperatures was demonstrated by Westlake *et al*. (14, 65). Results showed that bacterial enrichments obtained at 4°C (39°F) can degrade the same oil at 30°C (86°F) but at a reduced rate. However, bacterial cultures at 30°C (86°F) are unable to utilize the same oil at 4°C (39°F).

There is virtually no possibility of a fire occurring at an oil spill debris disposal site due to spontaneous combustion. Heat is released during biological degradation, but decomposition temperatures do not exceed 71°C (160°F), the limiting maximum temperature for microbial survival. Significantly higher temperatures are required to ignite most oils. Spontaneous combustion can theoretically occur in spill debris containing more reactive, cracked oil products, but such hydrocarbons would evaporate before combustion could occur in a debris mass. There has been no incidence of spontaneous combustion reported in spill debris or in oily waste products from petroleum refineries.

pH

The relative acidity or alkalinity of the interstitial regions of a soil will largely determine what types of microorganisms will flourish there. Yet the pH of the soil is dependent upon a number of other factors including the mineral content and composition and the presence of acidic organic detritus. In general, neutral or slightly alkaline pH will favor bacterial growth. Investigators report that the optimum pH range for the growth of various species of hydrocarbon-degrading *Pseudomonas* was between 6.0 and 9.0 (8). On the other hand, a pH below 6.0 tends to favor the growth of fungi. One technique that may be useful in the disposal of oil spill debris would be application of a buffering agent in the soil which would discourage fungal dominance. The role of certain clays (particularly montmorillonite) as soil buffers has been documented (1).

Organic Material

The presence of organic material in soil (other than the oil components themselves) can also influence the degradation of oil spill debris. Almost all microorganisms that are known to be capable of degrading hydrocarbons will preferentially metabolize alternative food sources (e.g., carbohydrates) if they are available. This could be a problem where oil spill debris disposal is attempted in organic-rich soils or where such debris is purposely mixed with organic-rich solid wastes.

Organic products of bacterial metabolism may be toxic to soil microorganisms. However, most microbial cell waste in soils is comprised of various polymers which may degrade further in the presence of oxygen to humic and fluvic acids, materials that are commonly found in soils. Westlake *et al*. (14) reports that ureaphosphate treated oil plots showed a more rapid rate of revegetation than was observed for control plots, thus indicating the residues remaining after microbial activity were not toxic to plants (14, 65).

Other Factors Affecting Oil Degradation Rates

Literature sources contain very little information concerning quantitative biodegradation rates of oil. Conflicting data from various studies illustrate the lack of standard procedures for measuring oil degradation rates. Some broad statements concerning relative degradation rates of various petroleum types can be made on the basis of some studies assuming all other conditions are equal (48).

Crude oils vary greatly in composition but consist qualitatively of hydrocarbons and compounds containing oxygen, sulphur, nitrogen, and trace amounts of metals (22). Hydrocarbons may be broadly classified as paraffins, cycloparaffins, and aromatics. Within these three families, thousands of combinations are possible, with their susceptibility to microbial oxidation varying according to the molecular weight and structure of each (65).

Hydrocarbons with high molecular weight, high viscosity, complex crystallinity, and/or toxic constituents tend to degrade at slow rates. Crystallinity is especially important. Paraffins, because they are straight-chained, are the easiest for microbes to degrade although the relatively low surface area available on paraffins acts as an impediment to degradation (57, 63). For oils with branched molecular structures, the rate of decomposition is drastically decreased. Cycloparaffins seem to be utilized poorly by microbes, but rates vary according to the molecular complexity of the ring structure (60). Aromatic compounds are utilized at a slower rate than the branched paraffins. The higher weight petroleums which usually contain the aromatic and cycloparaffinic rings and the paraffinic substitutes of the rings are the most difficult to oxidize (8, 17, 26). These petroleums include the bitumens and asphalts.

Overall, it can be generalized that straight chain medium molecular weight hydrocarbons (such as paraffins) are the most easily oxidized with cycloparaffins and aromatics progressively more resistent depending upon the complexity of their crystallinity (8, 59). This wide diversity in possible crystal combinations results in differential decomposition rates (55). Variances in the degradation of refined and unrefined oils create a further complication when attempting to quantify rates of degradation. Since refined oils generally contain a higher percentage of lighter, more toxic molecules, decomposition rates can vary widely (37).

Most research involved in defining this problem has shown that the utilization of hydrocarbons by individual isolates varies significantly. The pattern of high decomposition variability between hydrocarbons is one reason why reliable, quantitative decomposition rates for oils is lacking (63).

Time for Complete Oil Degradation

Degradation of oil contained in spill debris will occur within several months to several years under the most favorable aerobic conditions, depending upon environmental conditions such as temperature, nutrient availability, and moisture content. Thousands of years may be required under the most favorable anaerobic conditions. Thus, the particular method used for land disposal will determine how long the oil in oil spill debris will remain undegraded. Burial methods inhibit aeration and thus increase degradation time while landspreading promotes aeration and accelerates degradation.

All other factors being equal, waste oil in colder climates will degrade more slowly than in warmer areas. During the winter months, microbial activity may even cease in cold areas. But degradation will proceed even in the northern areas of Canada during summer months (14).

RELATIONSHIP OF OILY WASTE DISPOSAL TO VEGETATION

Many researchers have studied the effects of land deposited oil on various plant species. Results of those studies relevant to oil spill debris disposal are summarized here. The information is most directly related to the land cultivation method of disposal, since crops grown on land previously used as an oil spill debris spreading ground could contact the remaining oily material and degradation products. If properly buried, the oil debris in a sanitary landfill or burial site would be below the plant root zone and would thus not be likely to affect crops.

It is well known in oil producing regions that crude oil on land can inhibit crop growth. Vegetation can be affected for various reasons. For example, bacteria that convert the oil to organic matter create anaerobic conditions in the soil subsurface. It is largely the inability of plant roots to obtain sufficient oxygen and moisture which inhibits plant growth (45). Initial oil contact with soil usually stops plant growth because the volatile fractions enter the plants and seeds creating a debilitating narcotic effect (55).

The ability of plants to resist oil contamination is directly related to the depth of rooting, ease of replacing leaves, and the possession of storage organs or underground stems, particularly rhizomes (40). Researchers generally agree that large concentrations of oil may create immediate toxic conditions for plants.

The extent and duration of inhibited soil fertility depends largely upon the concentration and depth to which the soil is saturated with undegraded oil. Soil containing degraded oil will exhibit signs of increased fertility. Increase in soil fertility is attributed to a higher organic and nitrogen content produced by the nitrogen fixing bacteria and an increase in porosity and the moisture-holding capacity of the soil. Even fairly sensitive crops such as vegetables can tolerate a considerable quantity of crude oil in the soil (45).

For example, a study by Plice (45) showed that after one year, there were negligible differences between crops of wheat, barley, and rye grown on plots treated with oil as compared to corresponding crops grown in untreated soil. After three years, it was reported that the oiled plot produced yields approximately 20 percent higher than those from untreated plots. Carr found in his studies of soybean growth that light applications of oil actually improved growth (10).

The concentration at which oil addition is toxic to vegetation is of the order of 1 kg per m^2 of soil, depending upon vegetative and soil types. Even soils saturated to depths of more than 1.2 m (4 ft) eventually showed signs of increased productivity although the period required for soil reclamation was 7 yrs (9). It has been suggested that oil pollution damage to plants can be minimized by heavy fertilization (45). This action is probably a simple mass-action effect operating by forcing the necessary nutrients into the plant.

There is no indication that higher plants can utilize the energy content of oil for growth purposes. Plants will increase the rate of moisture loss and can complete with the microorganisms utilizing the oil for available nutrients. On the other hand, a number of studies have indicated that the microbial populations present in the rhizosphere are enhanced in both numbers and species diversity over populations in root-free soils. This is due in part to the release of amino acids and vitamins by plant tissue. The synergistic relationship is completed by the microbial production of metabolic by-products beneficial to plant growth.

Further study is required to define the extent to which rhizospheric bacteria are capable of degrading oil spill debris substrates and, if so, what the degradation rates are. The existence of plants may also increase oxygen requirements in the oil/soil mixture and root zone by providing more carbon in the form of root tissue.

The potential advantages of plant growth on the site could come from improved aesthetics, decreased surface runoff and erosion, and a ready visual indication of whether the soil moisture is adequate for biological decomposition of the oil. In rough terms, if vegetation is thriving, sufficient moisture is likely to be available for oil degradation as well as for plant growth.

Treatment and disposal of oil spill debris by landspreading can also create environmental problems. As noted, landspreading tends to increase volatilization of oils into the atmosphere. Also, potential reuse options for a landspreading site may be limited due to the presence of heavy metals and other contaminants at or within several centimeters of the soil surface. Preliminary studies have begun on the effects of growing edible crops on oily waste landspreading plots. Although no firm conclusions are available, it is clear that plants can take up heavy metals from the soil and concentrate them in their leaves and stalks. At this point, it is thought best to refrain from using vegetation grown on landspread sites for human or animal consumption until further information is available.

OIL SPILL DEBRIS DISPOSAL METHODOLOGIES

Oily wastes have been generated since the first discovery of oil in the nineteenth century. Methods of managing oil-bearing wastes have evolved in the oil refinery industry and are still changing today. Much of the technology applicable to the disposal of oil spill cleanup debris must be borrowed from the refinery industry, since very little attention has been devoted to this final necessary step in oil spill cleanup procedures. The literature contains little reference to operating procedures, environmental factors, or costs associated with oil spill debris disposal. Indeed, the primary reason for this subject study and manual is to fill this data void.

It should be emphasized that the oil spill debris requiring disposal could contain mostly oiled soil, vegetation, rocks, sorbents, and other solids collected during spill cleanup. Any excessive oil should have been recovered prior to or after debris collection but certainly before disposal. Also, in many cases, debris consisting largely of oiled soil can be used as a road base, reducing or eliminating the need for disposal.

Whatever debris remains after recovery of the usable fraction must be properly disposed of to ensure that any adverse environmental impacts at the disposal site are minimized or prevented. Four basic methods are available for proper debris disposal:

- Land cultivation (also called landspreading, landfarming, and land treatment): Debris is spread in thin layers and periodically mixed with soil to assure adequate aeration and mixing of soil microbes with the oily substrate;

- Landfilling with refuse: The oil spill debris is deposited in a sanitary landfill and buried along with mixed municipal refuse and/or compatible industrial solid waste and sludges and covered with soil;

- Landfilling without refuse (also called burial): The debris is deposited alone in trenches, canyons, or other suitable areas and covered with soil; and

- Lagooning: The debris is placed in a diked area and left to degrade and/or evaporate.

Other methods may have limited applicability. For example, oil spill debris can conceivably be composted. The composting process is akin to land cultivation except that the compost product is generally marketed instead of left in place. Given the poor demand for compost made from municipal refuse, oil spill debris based compost would probably not be a highly saleable item (12).

Note that this study is concerned only with land disposal alternatives. Investigation of incineration and other processing methods are beyond the scope of the project. However, such processing methods should definitely be considered if they are available and the debris is amenable for treatment.

There are no standard operating procedures for handling oil spill debris or similar wastes at a land disposal site. The basic goal for each disposal method is to receive the oily waste and process or sequester it as rapidly as practical so that environmental hazards are minimized. Available information pertaining to each of the four disposal methods is addressed below.

Land Cultivation (or landfarming, landspreading, or land treatment)

Land cultivation of oily waste materials is being practiced in various locales throughout the world. Primarily implemented at oil refineries to dispose of refinery wastes, the technique is deemed directly applicable to oil spill debris that does not contain excessively large or bulky solids, unless the bulky items are removed. Oil spill cleanup debris from at least two separate instances have been processed by landspreading, one in Utah and one in southern California. Conditions at both of these sites are described in detail in Part 2 of this volume.

The land cultivation process is known by various other terms, including landfarming, landspreading, and land treatment. Regardless of the name, the process involves spreading oily wastes thinly over the land so that subsequent cultivation and mixing will expose all oil to air and soil microbes. As previously noted, essentially all soils contain the bacteria, yeast, and fungi that can degrade oil (28). In the presence of oil, these bacteria can multiply to sufficient numbers to consume most of the oil even when only relatively small numbers are originally present.

The spreading process is continued until a large area is covered by the oily waste material. Nothing further is done until any water present has evaporated to such a point that a tractor can be driven over the surface.

A tractor-drawn rototiller, plow, or harrow is used to break up the oily crust and mix it with the soil organisms present in the surface layer of the soil. Practices vary from one location to another with respect to the frequency of such mixing. A common practice is to plow the material into the ground to a depth of about 15 to 20 cm (6 to 8 in) and to periodically aerate and blend the oily waste with soil. In the warm, humid southern United States, a rototiller may be used to mix soil and oily waste to depths of from 20 to 35 cm (8 to 14 in). As noted, it may not be necessary to mix at all if accelerated decomposition rates are not required. However, all practitioners of land cultivation contacted do till the soil/oil mixture at least twice per year for several years.

The application rates for oily waste material vary from about 2 to 5 cm (1 or 2 in) in thickness in the cooler, more humid northern parts of the U.S. and Canada to as much as 7 to 10 cm (3 and 4 in) in the warmer subtropical climates of the southwestern United States. Dependent on the thickness of the oil waste layer and the percent by weight oil content, the rate of degradation and disappearance of oil may require anywhere from one to two years or more.

It was calculated for one refinery where specific information was available that between 5.6 to 9.5 m^3 (1,500 to 2,500 gal) of oily sludge of approximately 1 to 1.5 percent by weight oil could be disposed of per 0.4 ha (1.0 ac) at each application (28). Dependent on the geographical area and other considerations, as many as two or three applications per year on the same plot of land appear to be possible.

Rudimentary laboratory analyses for one refinery indicated that a maximum of 6 percent by weight oil could be applied to their particular soil (28). The analyses also indicated that prescribed amounts of fertilizer should be applied concurrently with the application of oily sludge to aid in accelerating the rate of degradation and to provide essential nutrients where they are lacking.

Observations during oily waste degradation at one site indicate that the material changes from an oily, odorous, black sludge to a dried, cracked, cakey soot-like material which crumbles in the hand. The particular effect of oil degradation is dependent on soil and oil types.

Research into land cultivation methods and mechanisms has increased significantly within the last several years under the impetus of oil companies searching for economical techniques for treating oil residues from refining operations. Although petroleum refinery wastes are not necessarily similar to oil spill debris, the degradation mechanisms appear to be applicable for oil spill debris for the purposes of this report.

In general, research shows that the time required for complete oil degradation in soil at a land cultivation site is primarily a function of oil concentration (20). For example, in a 1938 study, various plots were treated using oil to soils ratios of 0.10, 0.20, and 1.1 to a depth of 15 cm (6 in). The oil was mixed with soil only at the first application. It was estimated that after 2 to 3 yrs, cultivation of most crops on all 3 plots could be resumed without detrimental effect upon the crop yields (32). (However, it is recommended that such vegetation not be eaten.)

A recent project at the Shell Oil Company's Houston Refinery has demonstrated that about 30.8 m^3 per ha per mo (3,000 gal/ac/mo) can be decomposed by land cultivation during the warm summer months. Other oil companies have reported decomposition rates varying from 0.10 to 22 percent of the total amount of oil in the soil degraded monthly. Fertilizer and weekly or monthly aerations were implemented during most of the studies. Research by other companies has shown much higher rates of degradation, as shown on Table 2. In the study by Shell Oil, a plot was disced to a depth of 15 cm (6 in) using an application of about 0.13 m^3 of oil per m^3 soil (1 gal/ft^3). At the 15 cm application depth, this loading rate is about 187 m^3 oil per ha (20,000 gal/ac) (20). Differences in decomposition rates and microbial species for the hydrocarbon types tested within the plot were minimal (50).

Oil application rates in land cultivation operations have been established mostly by trial and error experimentation. Basically, the goal is to apply as much oil as possible to a given area of land such that oil degradation rates are within acceptable limits. The limits depend on how long the land is available for oily waste disposal and/or how frequently oil is to be spread. An estimate of the optimum oil concentration in soil to promote degradation can be calculated, as described below.

For aerobic biological decomposition of oil in soils, oxygen must be transported through the soil to the oil. The major mode of oxygen transport in soils is via gas phase diffusion. Diffusion requires interconnected void spaces in the soils. But it is these same interstitial void spaces which contain the oil, water, and microorganisms. Thus, for any soil with a void fraction α, the oil content must be less than α if any significant oxygen transport is to occur. This provides an

TABLE 2. OIL DEGRADATION RATES AT SELECTED LANDSPREADING SITES (50)

(Values shown are in percentage reduction in oil concentration after one year)

	Location of Field Sites			
Type of Oil	Marcus Hook, Pa.	Tulsa Okla.	Corpus Christi, Texas	Average
Used crankcase oils	69.2	73.8	60.8	67.9
Crude oils	54.2	77.5	54.2	61.9
Home heating oil (#2)	86.0	90.0	86.0	87.3
Residual oil (#6)	48.5	65.5	59.4	57.8
Average	64.5	76.7	65.1	

absolute upper bound to the oil content in the range of 20 to 25 percent by volume.

Oxygen transfer can be approximately described by equation 14 (more refined form of equation 12):

$$Q = \frac{D_o\ (\alpha-\beta-\partial)}{\tau}\frac{dC}{dz} = \frac{D}{\tau}\alpha'\frac{\Delta C}{\Delta z} \qquad \text{(Eq. 14)}$$

where: Q = oxygen transport rate; g/cm^2 sec

α = void fraction of the soil (without oil or moisture)

β = oil fraction

∂ = water fraction

τ = tortuosity ≈ 3 for $\alpha' > 0.05$

$\alpha' = \alpha-\beta-\partial \approx$ net void fraction for gas phase transport

D = diffusion coefficient of O_2 in cm^2/sec

C = concentration of O_2 in in g/cm^3

But: $B = \frac{L}{z'}$

Where: L = mass loading of oil in g/cm^2

Therefore: $Q = \frac{Do}{\tau}\left[(\alpha-\partial)\frac{\Delta Co}{\Delta z} - \frac{L}{z}\frac{\Delta Co}{\Delta z}\right]$

For: $\Delta Co = Co$ (i.e., zero oxygen in biological reaction area) and $z = \frac{1}{2}z'$ (assuming the effective transport distance is ½ of the oil/soil mixture depth)

$$Q = \frac{Do\ 2}{\tau}\left[(\alpha-\partial)\frac{Co}{z'} - \frac{L\ Co}{z'^2}\right] \qquad \text{(Eq. 15)}$$

The optimum z for maximum O_2 transport can be derived as follows:

$$\frac{dQ}{dz} = \frac{2D}{\tau}\,Co\left[-\frac{(\alpha-\partial)}{(z')^2} + \frac{2L}{(z')^3}\right] = 0 \qquad \text{(Eq. 16)}$$

or $z' = \frac{2L}{(\alpha-\partial)}$

As an example:

- For $\alpha = 0.25$
- And $\partial = 0.1$ (10% moisture in the soil)

$$z' \text{ optimum} = \frac{2}{0.15}\, l = 13.3\ L$$

$$\text{Or } \beta \text{ optimum} = \frac{(\alpha - \partial)}{2} = \frac{1}{13.3} = 0.075 = 7.5\% \text{ oil by volume}$$

It should be noted that the optimal solution is independent of the $\Delta z = f(z')$ assumption.

This solution also shows that the oxygen mass transfer (and thus the possibility of aerobic oxidation) goes to zero when $\partial + \beta = \alpha$ or when all the voids in the soil are filled with either oil or water.

The foregoing analysis suggests that, as a general rule of thumb, oil should be applied and mixed with soil so that the oil concentration is in the range of 5 to 10 percent by volume. This soil loading would yield optimal degradation rates.

The Shell study also found that the addition of nitrogen and phosphate accelerated oil degradation rates. An oil degradation rate of 1.2 percent of the oil in the soil was obtained with fertilizer addition while similar plots without fertilizer degraded only 0.6 percent of the oil monthly (32). Weekly applications on test plots in combination with agricultural lime and fertilizer were shown to maintain pH and to supply sufficient nutrients for microbial growth (45). Furthermore, the Shell study indicated that irrigation with refinery wastewater effluents high in nitrate during extremely dry weather also aided microbial growth (32). Probably both the added moisture and nitrogen were beneficial.

Other research has shown that oil degradation by land cultivation can be aided by dehydrating the oil if too much water is in the soil-debris mixture. Artificial drainage has been reported beneficial in some studies (20).

An undocumented land cultivation operation in southern California routinely handles waste oils. Materials deposited at the site consist primarily of spent drilling muds, oil field wastes, and some waste petroleum products. The oily materials are mixed with indigenous sandy soil primarily by the action of dozer tracks. A disc is used occasionally. The oily characteristics of the waste are lost within one year.

Overall, observations at existing land cultivation operations show that oil refinery wastes and other oily materials can degrade within a period of several months in warm climates using closely controlled land cultivation methods. Similar decomposition rates could be expected for land cultivated oil spill debris as long as proper procedures are employed and various materials in spill debris don't hinder oxygen transfer to oil.

Soil characteristics at a land cultivation site are reported to change with time (9). In one instance, alkaline bentonite-like clay which had previously dried to a very hard cake-like material during dry periods changed to a soft loamy-like soil after land cultivation (9). This change was presumably due to increased organic and moisture content from the oil.

Detailed observations show that the oily sludge material does not completely degrade or disappear (28). A small fraction of the oil still remains combined with or interspersed between individual soil particles. Also, oil-conditioned soil appears to have a higher moisture content than the native soil. This is the result of a breakdown of the soil structure and dispersion of soil particles which result in a reduced percolation rate. Increased moisture retention capabilities have been noticed in several studies along with a notable waxy appearance of the soil (10).

There have been several reports and observations of luxuriant vegetation growth at land cultivation sites. In one instance, grasses were seeded naturally and grew to a height of 0.6 m (2 ft) in the area where oil was spread. This was far taller than any other vegetation in the area (28). Wild sunflower plants established thick stands on landspreading plots at Little Mountain, Utah (see case study reports, Part 2). In this case, the vegetation was evidently enhanced because of added urea and phosphate fertilizers, but oil in the soil apparently did not impede growth of this plant variety.

The incidence of precipitation may have little effect on land cultivation once the oily material is deposited and mixed. For example, results of a 2.5 cm (1 in) rainfall were observed approximately one week after application of oily sludge to a land cultivation operation. The oily sludge was not transported by runoff to the low-lying parts of the field, but appeared to be held in place by the soil. In those places where the water had puddled there were only slight traces of visible oil on the surface of the water (28).

Lagooning

In lagooning, oil spill debris is placed in a large shallow pit to degrade and/or promote evaporation of the volatile materials. Usually, no effort is made to mix or otherwise aerate the debris mass; the greater portion remains anaerobic.

No instances of oil spill debris disposal by lagooning have been reported, although the method has often been used for spent drilling muds and other oil field wastes. In general, the method would require the dedication of a plot of land for an indefinite period. Lagooning is more ameanable for debris containing no large or bulky items. However, land cultivation would be applicable for such debris, and the long-term maintenance of a lagoon would be unnecessary.

Both artificial membrane and soil liners may help to prevent outward migration of waste materials from disposal sites. Such liners may also be useful at lagoon sites for oil spill debris disposal, although the utility of man-made membrane liners over extended periods is questionable (27).

Landfilling with Solid Waste

Disposal of municipal and industrial solid wastes by sanitary landfill techniques is widely practiced in the U.S. Because many areas of the country operate sanitary landfills, they have often received oil spill debris. It is expected that sanitary landfilling will continue to be a major disposal method for debris.

It is important to note that all solid waste land disposal sites operated by municipalities or private companies are not necessarily sanitary landfills, nor are they properly sited and operated. Strict sets of criteria have been developed by EPA (Thermal Processing and Land Disposal of Solid Waste, Guidelines, Federal Register, Vol. 39, No. 158, Aug. 14, 1974), various state agencies, and engineering associations (such as the American Society of Civil Engineers Manual of Practice No. 39) (52), to control sanitary landfill development. Several important criteria must be met, including:

- Site location - the site should present no threat to ground or surface waters;
- Cover material - the wastes must be covered by a minimum of 15 cm (6 in) of suitable soil at the end of each day;
- Monitoring - where contamination from gas or leachate is possible, an appropriate monitoring program must be enacted;
- Development plan - an engineered plan including consideration of surface drainage, waste filling schemes, soil cover excavation areas, and access road construction, should be prepared for each site.

In many states, oil is considered a hazardous material, and therefore it must be deposited in a specially located and/or operated sanitary landfill. In such areas, it may also be necessary to dispose of oil spill debris in a special hazardous waste sanitary landfill. However, in the past, oil spill cleanup debris collected under emergency conditions has been deposited in conventional sanitary landfills, even in states where stric enforcement of waste disposal controls is in effect. Debris relatively free of liquid oil and water should not in itself cause leachate problems at a conventional landfill, assuming the volume of debris is small compared with the waste volume in place. Thus, the option of sanitary landfill disposal of debris is usually available to all.

It should be noted, however, that approval of local pollution control agencies may be relatively easy to obtain in comparison with public support. In at least one instance, oil spill debris was stockpiled for several months because local citizens were opposed to disposal of the material at nearby sanitary landfills.

Assuming that approval to deliver oil spill debris to a sanitary landfill is secured, no special problems should be encountered in its disposal. Oil spill debris delivered to a solid waste sanitary landfill for disposal is generally handled similarly to all other solid waste materials. The delivery vehicle is directed to a dumping location, and the landfill equipment spreads the deposited debris into the waste mass. Lifts of from 0.6 to 1.2 m (2 to 4 ft) are appropriate. Mixing with refuse will provide opportunities for oil and any water present to be absorbed and thus impede outward migration. As with all sanitary landfills, the oil spill debris must be covered daily to prevent infiltration of precipitation and exposure of debris to site users. Also, some spill debris may contain organic material such as seaweed which is attractive to flies and rodents. Daily covering will discourage the attraction of these pests.

A properly situated and operated sanitary landfill can adequately protect underlying and surface waters from oil spill debris contamination. However, not all sanitary landfills or waste disposal sites are properly located with respect to water resources. In at least one instance, oil spill debris was washed from a landfill back to sea by flood waters, simply because the disposal site was located in a known flood plain. Also, waste oil lagoons have been flooded during a major storm, causing an oil spill concurrently with flood damage (54). Operational procedures may also be faulty. Such problems are often encountered at older landfills which were initiated prior to current improvements in technology and promulgation of stronger state and federal standards. In those states that classify oil as a hazardous material, it may be that oil spill debris must be deposited in specially designated landfills which afford natural protection to waters. Furthermore, the disposal site operator often is required to bury the debris as soon as practical after it is received. Site selection and operation procedures described in the manual (Volume I) are intended to guide selection of proper landfills as the final depository for oil spill debris.

Deposition of oil spill debris with refuse in a sanitary landfill is a commonly practiced disposal method. However, no data has been obtained on the degradation rates of oil spill debris or the entrained oil sequestered in landfills. From numerous studies of sanitary landfills, it is known that anaerobic conditions prevail in the landfill environment and that essentially all waste decomposition is anaerobic. Thus, oil is expected to be one of the last materials to decompose, if indeed it ever does. Estimates of the time for total decomposition range from 5 to 100 years or more, although the latter is probably a more realistic estimate in an anaerobic environment (45).

Landfilling Without Refuse (or Burial)

Landfilling or burying oil spill debris in a separate area is another commonly practiced disposal method, particularly when conventional sanitary landfills are relatively inaccessible to the oil spill site or if landfill operators are unwilling or unable to accept the debris. Debris may be buried either below grade in excavated trenches or abandoned quarries or above-grade over properly prepared subsoils with appropriate barriers or berms placed around the disposal site perimeter.

In the past, sites with underlying impervious soils were selected as a fail-safe guarantee that oily material would not leach from the disposal area. In the absence of naturally occurring areas with such conditions, imported clay barriers have been placed to seal the disposal areas.

In selecting a secure site for burial without refuse, a set of minimum site selection criteria should be observed:

- The site should be as far as possible from surface water intakes and active faults. One study has suggested the following criteria (36):
    - 610 m (2,000 ft) to any well;
    - 8.1 km (5 mi) to municipal wells or static water intakes;
    - 1.6 km (1 mi) upstream of a river intake;

  - 1.6 km (1 mi) from an active fault.

- The site should not be selected if it occurs in the water table or is readily susceptible to washouts from floods (51).

- Distances from the bottom of the pit to the known groundwater should be maximized to take advantage of the soil attenuation capacity.

- The disposal pit should be lined with a tight clay such as bentonite. Permeabilities of 10^{-8} cm/sec or less are desirable. The pit floor should be graded so that any liquid that seeps from the debris will collect at a pump sump.

- If liquid effluent is expected, leachate drainage, collection, and storage facilities should also be constructed. Leachate from the collection facility should be transported to an acceptable treatment plant. Figure 7 illustrates the specifications for one oil spill debris disposal burial site developed by EPA personnel in New England (30).

- Trenches or channels should be installed upstream from the pits to divert any overland water from the area.

- Oil spill debris should be placed in the pit and covered with intermediate layers of dirt if necessary to facilitate equipment operation.

- When the disposal operation is complete, a final layer of cover dirt from 0.6 to 1.2 m (2 to 4 ft) deep should be placed. If the debris contains biodegradable solids such as vegetation, the final cover should be mounded to compensate for eventual settlement of debris upon anaerobic decomposition (51).

- It may be advantageous to place a perforated plastic pipe along the top of the buried waste (possibly in a gravel layer) with one end bent vertically through the cover material to vent the accumulated gas. Venting by means of vertical sand seams has also been proposed.

- Monitoring wells and/or other facilities have been installed at only a few landfill sites to date. All future sites should provide a means to monitor the environmental conditions in and around the debris.

As with landfilling with refuse, burial of oil spill debris without refuse creates an anaerobic environment which is nonconducive for oil degradation. Visual observation of oil spill

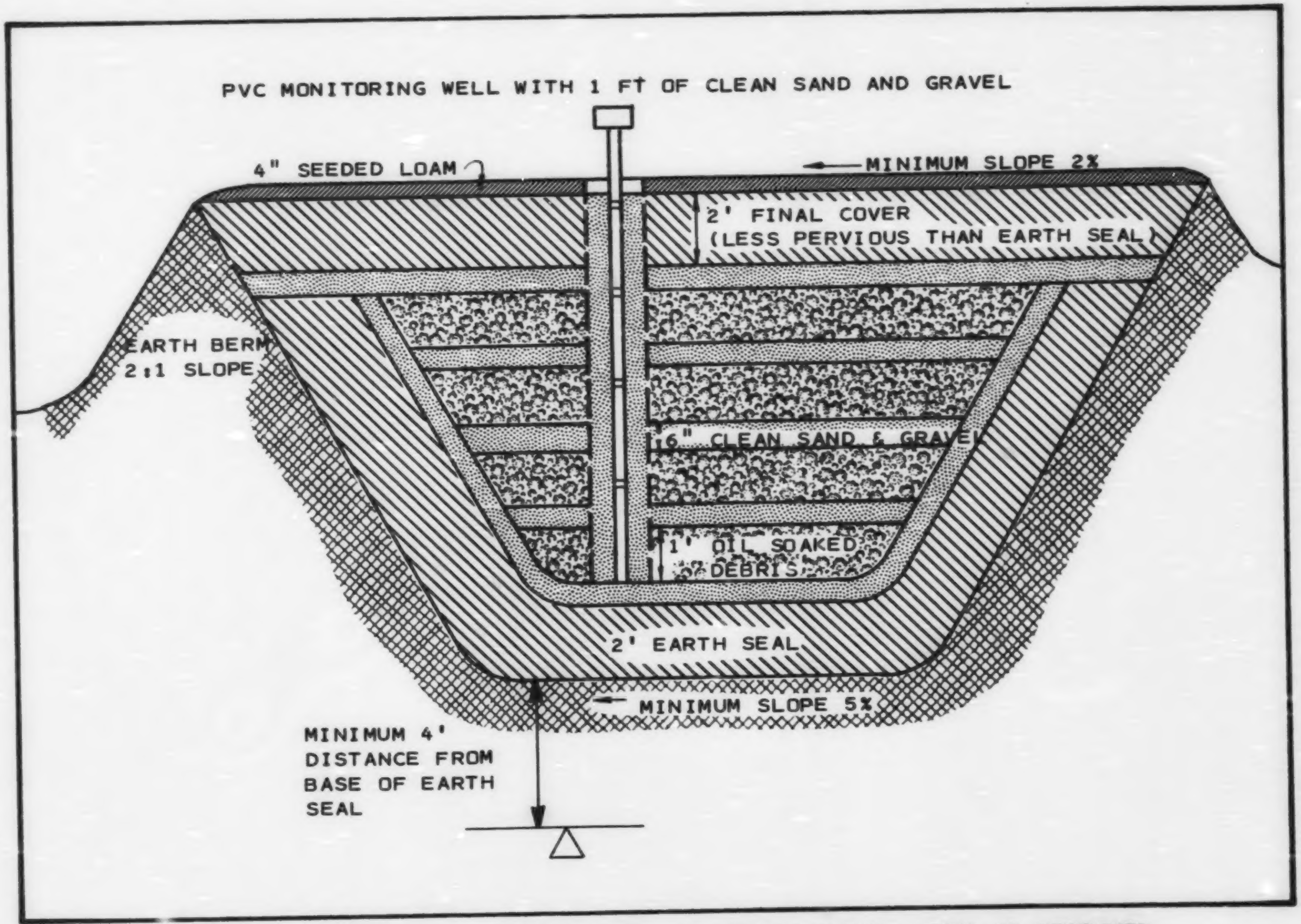

PVC MONITORING WELL WITH 1 FT OF CLEAN SAND AND GRAVEL
4" SEEDED LOAM
MINIMUM SLOPE 2%
2' FINAL COVER
(LESS PERVIOUS THAN EARTH SEAL)
EARTH BERM
2:1 SLOPE
6" CLEAN SAND & GRAVEL
1' OIL SOAKED
DEBRIS
2' EARTH SEAL
MINIMUM SLOPE 5%
MINIMUM 4'
DISTANCE FROM
BASE OF EARTH
SEAL

FIGURE 7. SCHEMATIC CROSS-SECTION OF DEBRIS BURIAL SITE AS DESIGNED AND CONSTRUCTED (AFTER JONES, REF. 28).

debris buried in the Santa Barbara and San Francisco, California, areas indicates little if any degradation after 3 to 5 years.

Comparison Between Methods

The on-scene coordinator at an oil spill cleanup may or may not have various options open for disposal of the oil spill cleanup debris. If he is free to chose the type of disposal he deems appropriate, a comparison between the basic methods is useful.

Table 3 summarizes factors related to the disposal methods. (Lagooning is not considered because of its limited applicability). Most information is from personal interviews and experience; little if any of the data is published in the literature.

Estimated Disposal Costs

The cost of each debris disposal method is highly dependent on site-specific conditions such as the debris volume and composition, needs for access road construction, types of equipment used, and prevalent labor wage rates. Of course, land costs can vary significantly.

The estimated range of unit costs to dispose of oil spill debris by the three methods is shown on Table 3. These costs do not include expenditures for land purchase or lease or access road construction. Also, the costs to transport oil spill debris from the spill location to the disposal site are not reflected. In general, land cultivation costs are reportedly higher than the other methods because more equipment and personnel time are required. Landfilling with refuse is likely to be the least costly debris disposal method since the waste material is incorporated into an ongoing burial site; the equipment and personnel costs are shared by other wastes deposited at the site.

Approximate unit costs of operating the type of equipment likely to be used at a disposal operation are summarized on Table 4. Also shown are other unit costs for other aspects of debris disposal operations. These data may be useful in estimating disposal costs for a given volume of oil spill debris by a particular disposal method.

The following hypothetical example illustrates the use of these data in estimating oil spill debris disposal costs:

An oil spill has been cleaned up resulting in an estimated 800 m^3 (1,040 cu yd) of stockpiled debris. The debris contains about 15 kiloliters (4,000 gal) of crude oil and appears suitable for land cultivation at a pre-selected 2 ha (5 ac) site 13 km

TABLE 3. COMPARISON OF LAND DISPOSAL METHODS FOR OIL SPILL DEBRIS

Method	Operating Factors		Environmental Factors	Estimated Costs
	Equipment Needs	Flexibility		
Land cultivation	- tractor - rototiller, disc, harrow, or plow	- adaptable to many areas - requires no special skills - access road may be req'd	- minimal hazards if runoff controlled; - no danger to groundwater; - no spontaneous combustion problems; - land may be tied up for disposal only temporarily (2-3 years).	$4 to $8 per cy (not including cost to construct access roads, if any)
Landfilling with refuse	use equipment available at landfill; generally a D-6 sized track dozer or larger	- for relatively small volumes of debris most landfills can readily accept; - many landfills available; - stockpiling usually unnecessary.	- improper landfill location may cause undue threat of oil pollution; - refuse can act as sorbent to impede flow of oil and contaminated water from site; - possibility of spontaneous combustion; - continuous long-term dedication of land to waste disposal.	$0.80 to $3.00 per cy
Burial	1 - D-8 sized tractor or larger. 1 backhoe may be necessary.	- stockpiling may be necessary; - access road may be required.	- oil will remain undegraded at site for more than 100 years; - a plot of land, heretofore unused for waste disposal, will be dedicated for such long-term usage.	$1.50 to $5.00 per cy (not including cost to construct access road, if any)

TABLE 4. ESTIMATED UNIT COSTS FOR OIL SPILL DEBRIS DISPOSAL OPERATIONS

Item	Unit Cost[1] ($/unit)
1. Access road construction[2] (if needed)	4.50 to 5.00 per ft
2. Site preparation (clearing, scarifying, grading, where necessary)	600 to 700 per ac
3. Drainage channels[3]	0.50 per ft
4. Application of fertilizer, other soil amendments (for landspreading only, if necessary)	180 to 200 per ac per application
5. Excavation and covering of trenches (for burial without refuse)	1.00 to 1.30 per cy
6. Mixing debris with soil (initial and periodic mixing of debris with soil)[4]	80 to 100 per ac per mixing period
7. Monitoring well installation[5]	180 to 250 or more per well
8. Seeding surface of disposal area (landspreading or burial site) with grass	180 per ac
9. Site geophysical and engineering studies	10 to 12% of site development costs
10. Transportation of debris to site[6]	0.05 to 0.07 per cy per mi

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[1] All costs in 1976 dollars.

[2] 20 ft wide, gravel road.

[3] Dirt trench.

[4] Assumes a D-7 size track dozer pulling a rototiller covering 5 ac per day.

[5] Depends on many variables, including soil type, depth to groundwater (if any), and drill rig used.

[6] Assumes dump truck or tractor-trailor rig.

TABLE 4 (continued)

Item	Unit Cost ($/unit)
11. Sanitary facilities, water and communications (at remote landspreading and burial sites)	50 to 100 per day
12. Contingencies @ 15% of	12 to 15% of site development costs
13. Disposal gate charge at sanitary landfill[7]	0.80 to 4.00 per cy
14. Laboratory Analysis	
oil content	25-50 per sample
organic acid	10-20
pH	5-7

---

[7] Charge varies significantly depending on geographical area.

(8 mi) from the stockpile area. A 244 m (800 ft) gravel access road is needed to facilitate debris delivery from the main road to the spreading area. The soil is sufficiently fertile to obviate the need for amendments.

Estimated cost to transport and landspread this debris at this site are $10,300, as shown on Table 5. In this hypothetical case, disposal of the debris at a suitable sanitary landfill within 160 km (100 mi) of the stockpile area would be more economical. However, a suitable site may not be available and land cultivation may be desirable since the oil is degraded.

TABLE 5. EXAMPLE COST ESTIMATE FOR HYPOTHETICAL OIL SPILL DEBRIS LAND CULTIVATION OPERATION

Item	Units	Unit Cost, $	Extension
Access road	800 ft	4.80	$3,840
Site preparation	5 ac	650	3,250
Drainage	170 ft	0.50	90
Landspreading	5 ac	90	450
Geophysical and engineering studies	$7,600	10%	760
Misc. facilities			150
Disposal operation contingencies			1,280
Subtotal, Disposal Operations			$ 9,820
Transportation of debris from point of collection to disposal site	1,000 cy	$0.06 per cy per mi	480
Total Cost to Transport and Dispose of Debris			$10,300

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PART 2

CASE STUDIES OF OIL SPILL DEBRIS DISPOSAL SITES

OVERVIEW

Four case study sites were investigated to provide further information on the acceptability of and potential problems associated with oily waste disposal on land. The purpose of each case study was to document the history of oily waste disposal and to report on observed environmental impacts at each site. Field investigations involved placement of wells through the oil spill debris and around the periphery of each site.

The case study sites were selected on the basis of information provided by various federal, state, and local officials responsible for past oil spill cleanup efforts and private contractors who have been involved in oil spill cleanup and disposal activities. Relatively few debris disposal sites were located during this project, attesting to the past problems of site location and procurements. Many instances of debris open burning were reported, for example. Those sanitary landfills that have received oil spill debris in the past were not suited for this study because the precise area of debris deposition within the landfill boundaries could not be accurately located.

Table 6, Summary of Case Study Site Information, shows that the four case study sites represent diverse geographical, climatological, and disposal operation characteristics. Table 7 summarizes the conclusions drawn from the field monitoring and laboratory analyses of soil, debris, and groundwater samples. It should be noted that the field and analytical work in all cases provides only a preliminary indication of environmental conditions. More extensive studies would be required to fully document the environmental effects, if any, of oily waste disposal at these sites.

Furthermore, evaluation of conditions at one site in light of the soils and other physical data obtained during well installation and from sample analyses suggest that the wells may not be suitably located to detect lateral oil migration through soil if it were occurring. Table 8 indicates the expected extent of oil migration through soils in comparison with the

TABLE 6. SUMMARY OF CASE STUDY SITE INFORMATION

Item	Case Study Site			
	A	B	C	D
Location	So. Calif. (coastal)	Little Mountain, Utah (near Ogden)	No. Calif. (coastal)	Cranston, Rhode Is. (near Providence)
Climate				
Annual ppt.				
cm	36.9	43.4	52.8	100.7
in	14.5	17.1	20.8	39.6
Avg. annual temp.				
^{o}C	15	10	13	9
^{o}F	59	51	56	49
Method of oily waste disposal	Land cultivation	Land cultivation	Burial	Burial
Type of oily waste rec'd.	Drilling muds, some debris	Liquid waste oil, little solids	Oily sand, some seaweed	Oily sand, rocks, and other solid debris
Soil type at site	Beach sand to approx. 7 m	Loam and sandy loam	Sandy loam to 2.5, then shale	Sandy loam and loamy sand
Depth to groundwater				
m	3	No water	4	3.5
ft	10		13	12

TABLE 7. SUMMARY OF ENVIRONMENTAL CONDITIONS AT EACH CASE STUDY SITE

Item	Case Study Site A - So. California	 B - Utah	 C - No. California	 D - Rhode Island
Surface appearances	Tilled farmland, some provided liquid with oil sheen. No vegetation.	Tilled farmland. Lush vegetation, especially on plots treated with high urea and phosphates.	Similar to surrounding land. Disposal site not readily discernable.	Above-ground fill, lush vegetation on top. Eroded side-walls.
Odors	Slight oil odor	None noticeable	None noticeable	None noticeable
Oil migration through soil away from disposal area?	Yes; oil detected in soil samples 7 m (20 ft) below site and 100 ft downstream off-site.	None detected	None detected	None detected
Groundwater contamination	Oil detected in non-potable water under site; source is not definitely disposal site.	No groundwater detected.	Oil detected in off-site well; source is not definitely disposal site.	Some oil detected. Source not definite.
Degradation of oil	Oil degrades within about 1 yr.	Oil degrades within 3 to 4 yrs.	No degradation noted.	No degradation noted.

TABLE 8. COMPARISON OF THEORETICAL OIL MIGRATION DISTANCES WITH OFF-SITE WELL LOCATIONS AT CASE STUDY SITES

Site	Classification	Permeability	Porosity %	Time since first oil deposit-yrs	Theoretical migration dist. m	Distance from edge of oily waste deposit to off-site well, m
A	sand	0.16	45	22	4,336	24
B	loam	4.2×10^{-3}	40	2	11	None placed
C	sandy clay loam	1.3×10^{-3}	30	5	9	16
D	loamy sand	1.6×10^{-2}	35	2	42	6

actual distance of off-site soil sampling at each of the four case study sites. The maximum distance of migration is a function of various factors, including:

- Time since the debris has been deposited on land;
- The type of oil in the debris;
- The degree of oil emulsification with water;
- The porosity and permeability of the soils;
- The annual average temperature and precipitation; and
- The depth and velocity of groundwater.

The minimum expected distance of oil flow through soils can be approximated by the following equation:

$$D = V \times T \qquad \text{(Eq. 17)}$$

where D = distance

T = time

$V = Ks$ where
V = rate of water moving through a unit cross section area
K = coefficient of permeability
s = gradient in direction of flow

Had all available data concerning each case study site been available prior to planning and placement of monitoring wells, several wells may have been located closer to the debris disposal area. For example, Well D at Site C appears to be too far off-site to have intercepted any oil migrating through the soil, since theoretically, oil cannot migrate to the location of Well D within the time period available. (The source of oil detected in Well D could not be determined from data obtained during these studies.) On the other hand, Well D at Site A is well within the expected range of oil migration, if any migration occurred.

Evaluation of the four operations studied here suggest that proper site selection is the most important decision facing persons responsible for oil spill clean-up debris disposal. Land cultivation at Site A does degrade the oil but because of porous subsoils, some undegraded oil does apparently migrate to underlying groundwater and laterally away from the disposal area. No such migration was apparent at Site B.

Proper engineering design can possibly substitute for lack of ideal soil and geohydrological conditions, as evidenced by the apparently acceptable burial site at Site D. Encapsulation of the debris mass in fine-grained soils allowed use of a portion of an abandoned sand and gravel pit for disposal.

Both the land cultivation and burial techniques appear acceptable for disposing of oil spill debris, judging from these case studies. Suitably flat and tillable land must be readily available to implement land cultivation and the debris cannot contain large rocks or other rigid items.

The history of each case study site and field monitoring activities are discussed in the following four sections. Note that the case studies are referred to as Sites A, B, C, and D. Specific locations of the two privately owned and operated disposal sites (Sites A and C) are omitted. Also presented are data from sample analyses and preliminary conclusions drawn from the data. Recommendations for further monitoring and sample analysis are provided where appropriate. References to data sources are listed at the end of each case study section.

SECTION 1 - CASE STUDY SITE A, SOUTHERN CALIFORNIA

Background

Oily wastes from nearby oil drilling and storage activities, including some oil spill debris, have been disposed of for many years using land cultivation techniques at an oil sump in Ventura County, California. A sampling program was instituted at this site in conjunction with the project to obtain oil degradation and migration data regarding an operational land cultivation facility. Although most of the oily material processed at Site A has not been debris from spills, information regarding the land cultivation methodologies and the operation's environmental impacts are considered applicable to similar disposal procedures applicable for oil spill debris.

Site A is located approximately 113 km (70 mi) northwest of Los Angeles on the coast of southern California. The Ventura County coastal area is indicated on Figure 8. The oily waste disposal site is situated on beach sands approximately 365 m (1200 ft) from the Pacific Ocean. The site is roughly rectangular; present land cultivation activities are confined to a 12 ha (30 ac) parcel on the western portion, as indicated on Figure 9. A dirt road serves the site and provides access for vacuum trucks which deliver most of the waste to the site. A 1.82 m (6 ft) earthen berm has been maintained on the west and southern extremities to contain the liquid oily wastes on site.

Topographically, the site is located at the mouth of a wide alluvial plain which empties into the Pacific Ocean. The plain is characterized by a relatively level relief. Site A itself exhibits a gradual western sloping relief of approximately 1.5 to 3 m (5 to 10 ft) due primarily to on-site grading.

Prior to its use as a land cultivation operation in 1954, the site consisted of Pleistocene dune sands which are still visible to the west. Since 1954, the land has been utilized for land cultivation of oily wastes. Surrounding land use has been primarily agricultural but is now being developed for residential purposes.

Climate

Climatological data for the area is summarized on Table 9 (1). As shown, annual precipitation averages about 37 cm (15 in). Temperature varies from lows of 6°C (42°F) to highs of 23°C (73°F) (2). West and northwesterly prevailing winds are frequent.

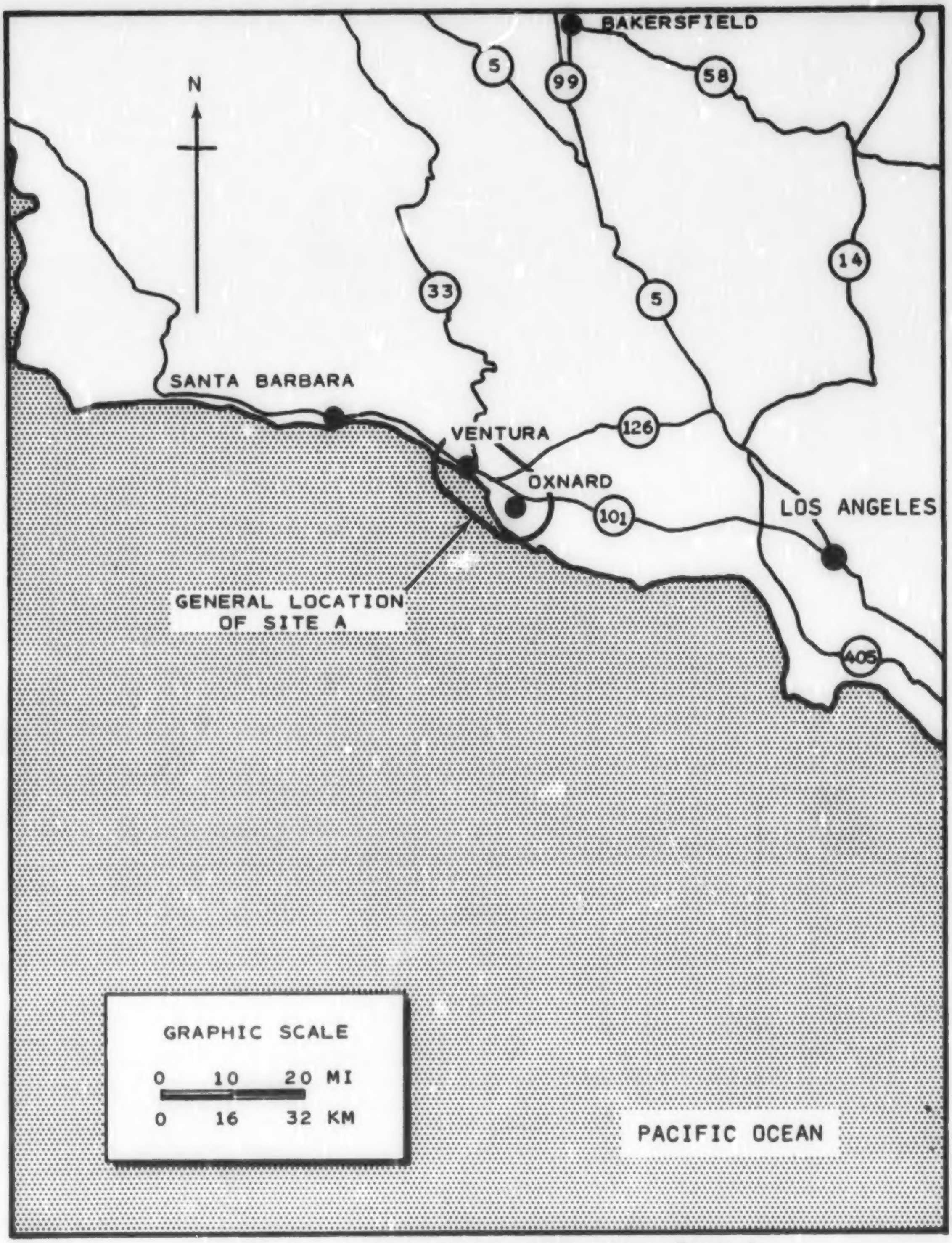

BAKERSFIELD
N
5
99
58
14
33
5
SANTA BARBARA
VENTURA
126
OXNARD
101
LOS ANGELES
GENERAL LOCATION OF SITE A
405
GRAPHIC SCALE
0 10 20 MI
0 16 32 KM
PACIFIC OCEAN

FIGURE 8. LOCATION OF CASE STUDY SITE A.

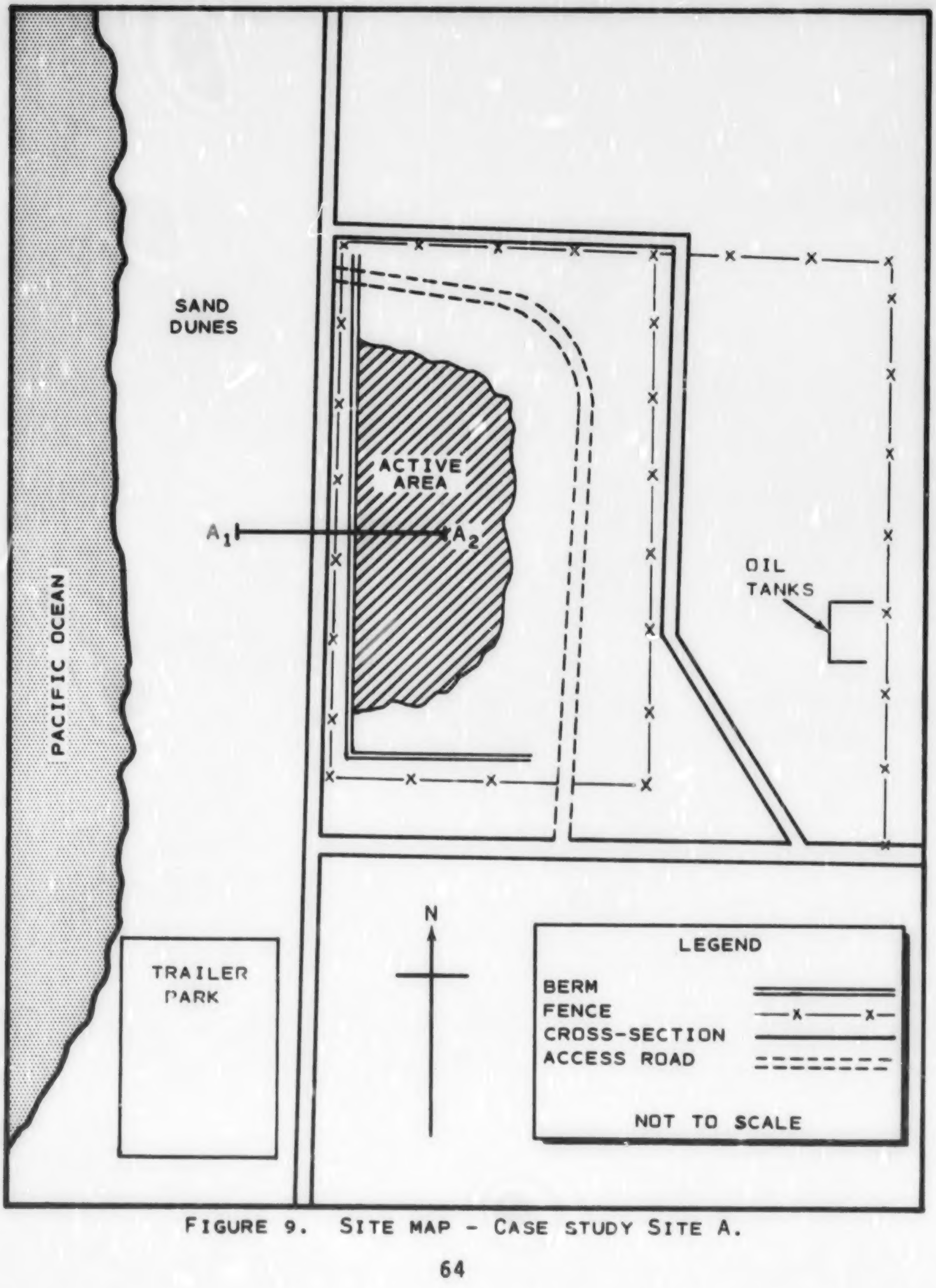

SAND DUNES
PACIFIC OCEAN
ACTIVE AREA
A_1
A_2
OIL TANKS
TRAILER PARK
N
LEGEND
BERM
FENCE
CROSS-SECTION
ACCESS ROAD
NOT TO SCALE

FIGURE 9. SITE MAP - CASE STUDY SITE A.

TABLE 9. SUMMARY OF CLIMATOLOGICAL DATA CASE STUDY SITE A

Month	Average Monthly Temperature*		Precipitation (annual)*		Evaporation+	
	°F	°C	in	cm	in	cm
Jan.	53.3	12	3.3	8.4	2.2	5.6
Feb.	53.9	12	2.9	7.4	3.1	7.9
March	55.2	13	2.2	5.6	3.4	8.6
April	57.2	14	1.1	2.8	6.1	15.5
May	59.4	15	0.1	0.3	6.8	17.2
June	61.5	16	0.1	0.1	8.4	21.3
July	64.8	18			9.4	23.9
Aug.	65.2	18		0.1	8.0	20.3
Sept.	64.5	18	0.1	0.2	6.7	17.0
Oct.	62.2	17	0.4	1.0	4.5	11.4
Nov.	58.6	15	1.1	2.9	3.4	8.6
Dec.	55.2	13	3.2	8.1	2.4	6.1
Annual	59.3	15	14.5	36.9	64.4	163.4

* Based upon 1931-1960 data.

+ Based upon 1974 data.

Geology and Soils

Information on the site's soils, geology, and hydrology was obtained from available published reports and from observations during well borings on March 19, 1976, performed as part of this project.

The land cultivation operation lies in an area defined by the United States Geological Survey as inactive dune sands which parallel the ocean for several miles north and south of the site (3). These fine sands extend inland approximately 914 m (3000 ft) where they form a contact with fine-grained, relatively impermeable, alluvium sediments of Pleistocene Age (see Figure 10). The dune sands are relatively uniform in size, thus, enhancing the opportunity for adsorption of percolating waste oils and subsurface aeration. Sand depths are from approximately 4.5 to 9.1 m (15 to 30 ft) in this area. A typical soil profile to a depth of 9.0 m (30 ft) is shown on Figure 11. The first 4.6 m (15 ft) is derived from sieve analyses. Figure 12 shows the well logs for all wells drilled at Site A.

Below the permeable dune sands are several centimeters of unconsolidated cobble-sized gravels which were encountered in three of the well hole corings at the site. An impermeable layer of clastics 45-60 m (150-200 ft) thick underlies these gravels and provides an effective aquiclude for any further vertical infiltration of waters.

Groundwater

Subsurface hydrology at the site is composed of 1) shallow perched water at about 9.1 m (30 ft) deep, and 2) the deeper Oxnard aquifer at about 60 m (200 ft). The Oxnard aquifer is a water supply for the area; the shallower aquifer is not. Since there is no hydraulic continuity between the deeper Oxnard aquifer and the shallower perched water, any infiltration of oily wastes could affect only the perched water. Characteristics of the perched groundwater system are addressed below.

The perched water table is defined vertically by the impermeable sediments and horizontally by the ocean and inland sediments. Since there is little or no contributing recharge from the inland sediments, precipitation and runoff are the only recharge sources of this perched water. Seasonal fluctuations are radical, ranging from several meters above the aquiclude to total saturation of the sands during periods of intense precipitation. Movement of this perched water is assumed to be seaward where discharge occurs. Figure 13 illustrates the estimated groundwater elevations and direction of movement based upon static water levels on March 19, 1976. The seawater tidal range in the area is .9 m to 1.2 m (3 to 4 ft) and probably affects the movement of this water; the degree is unknown. Conductivity

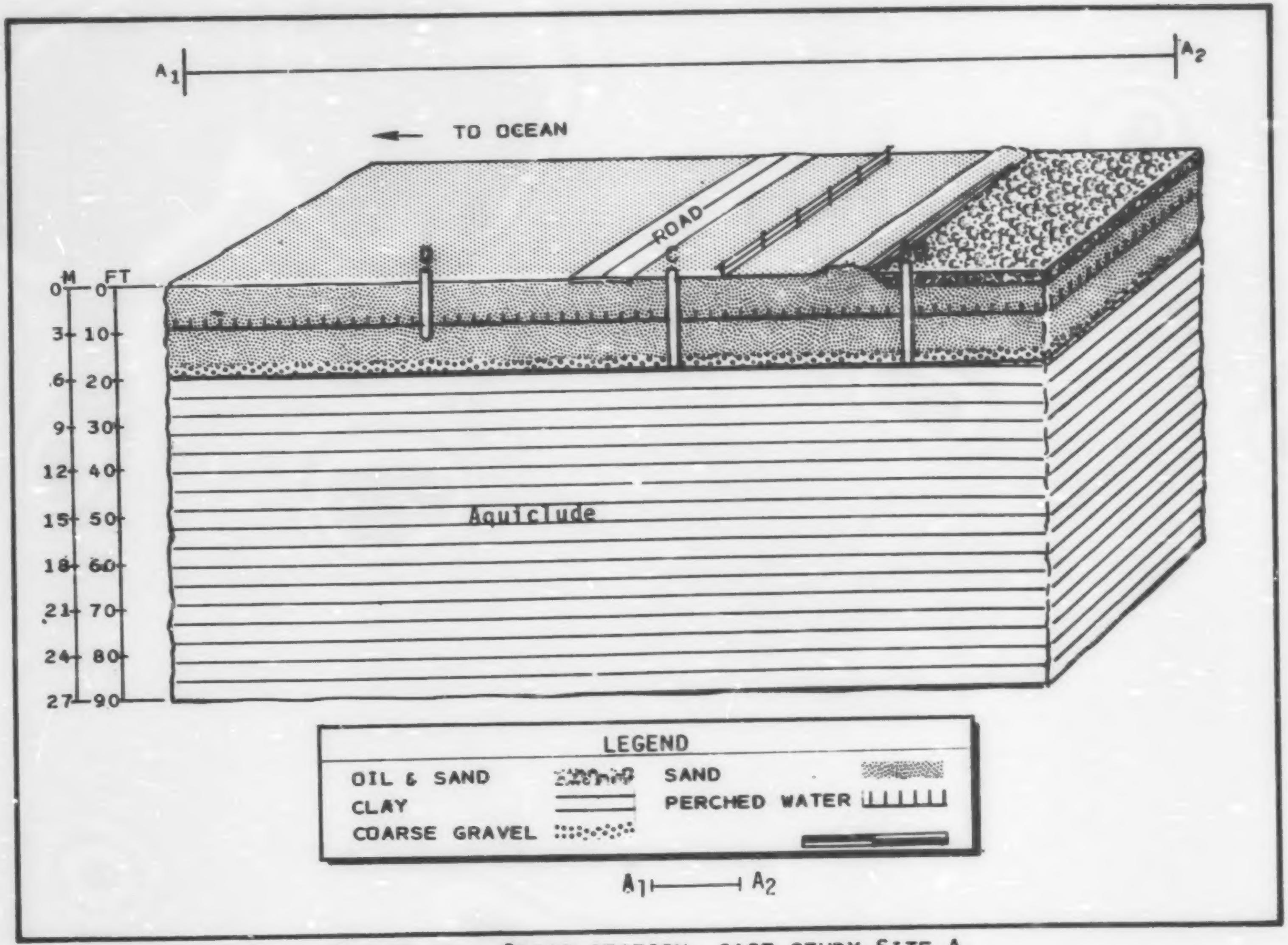
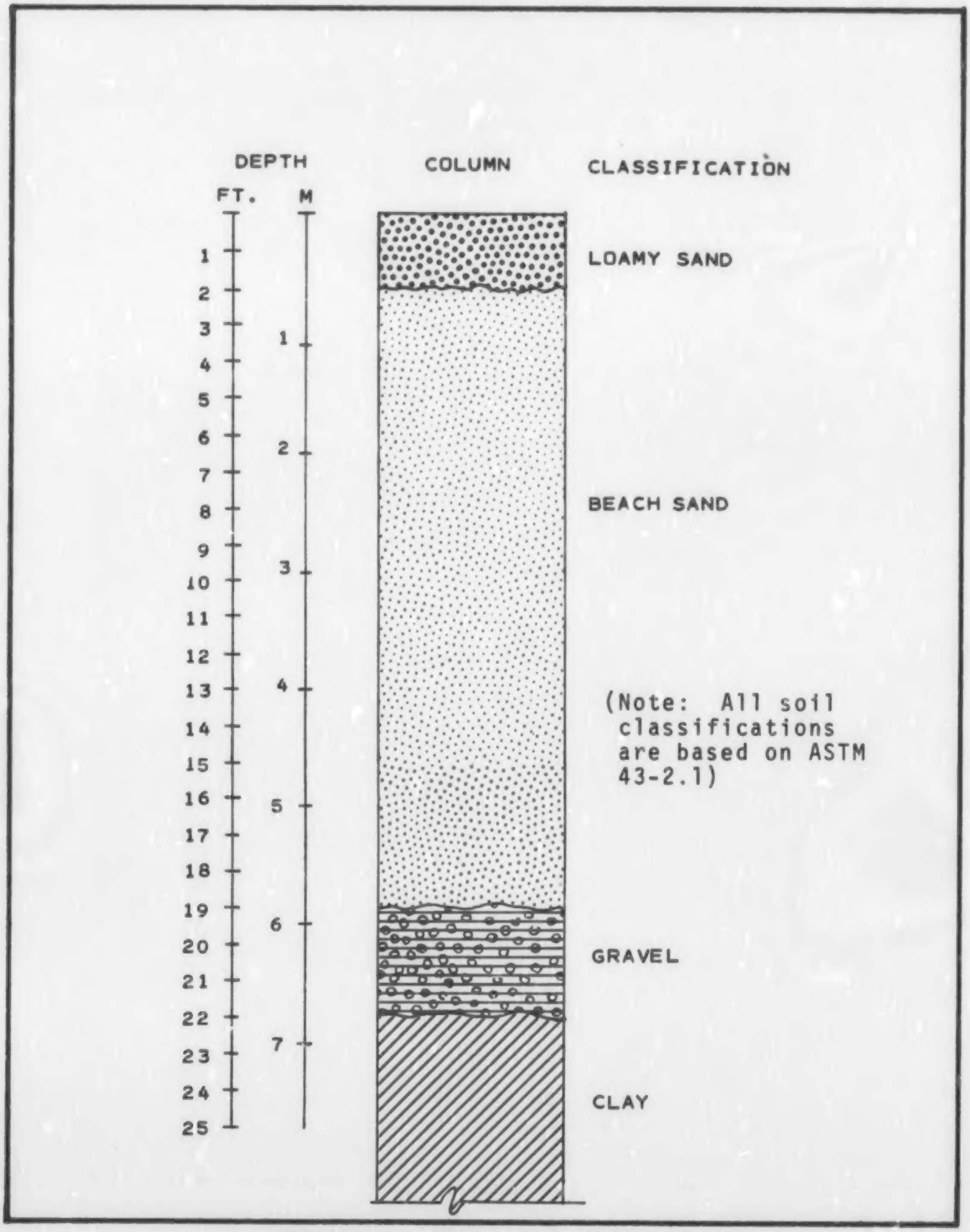

A1
A2
TO OCEAN
ROAD
D
C
Aquiclude
M
FT
0
3
6
9
12
15
18
21
24
27
0
10
20
30
40
50
60
70
80
90
LEGEND
OIL & SAND
CLAY
COARSE GRAVEL
SAND
PERCHED WATER
A1
A2

FIGURE 10. CROSS-SECTION, CASE STUDY SITE A.


DEPTH
FT.
M
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
1
2
3
4
5
6
7
COLUMN
CLASSIFICATION
LOAMY SAND
BEACH SAND
GRAVEL
CLAY

(Note: All soil classifications are based on ASTM 43-2.1)

FIGURE 11. TYPICAL SOIL PROFILE
CASE STUDY SITE A.

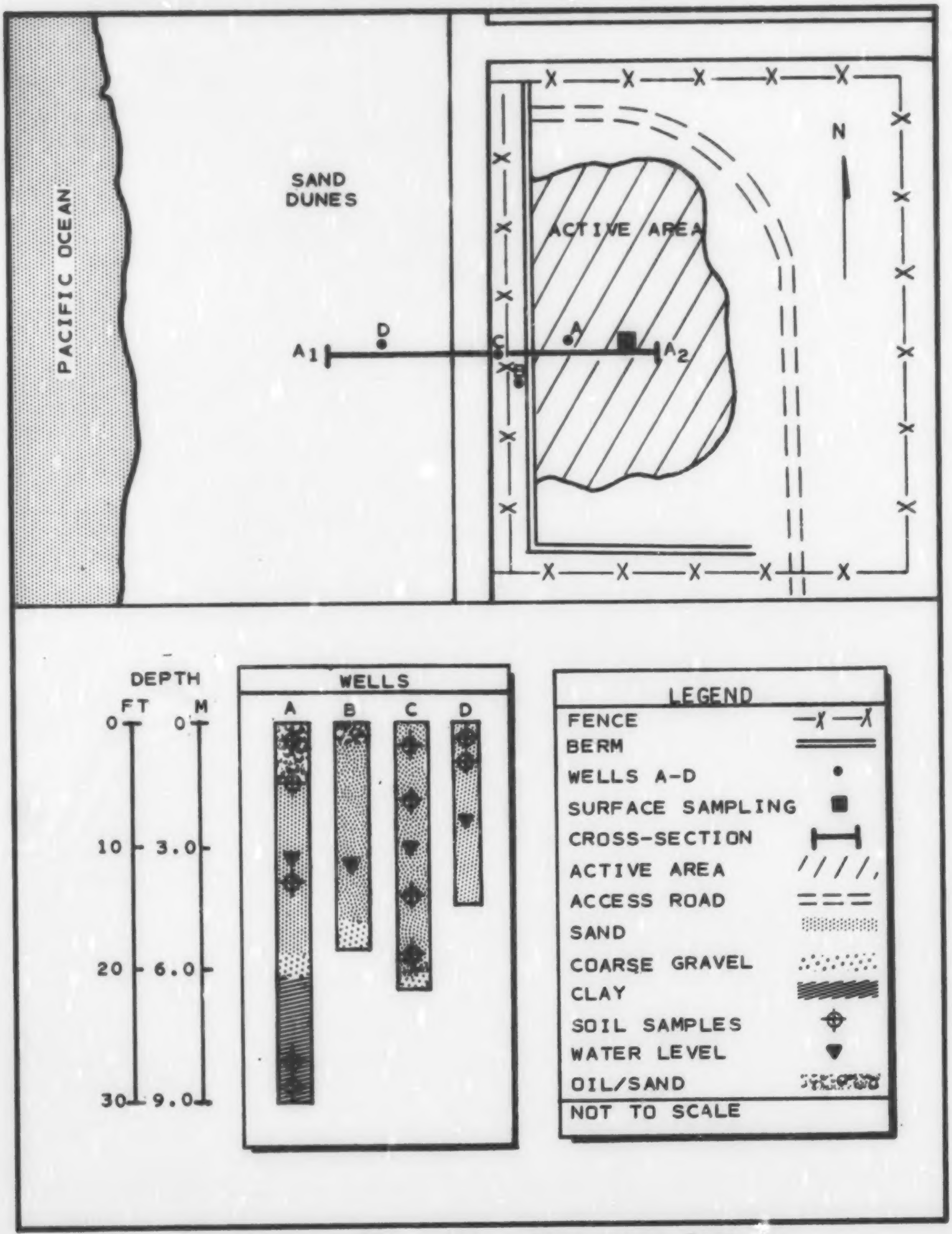

PACIFIC OCEAN
SAND DUNES
ACTIVE AREA
N
D
A
C
B
A1
A2
DEPTH
FT
M
0
0
10
3.0
20
6.0
30
9.0
WELLS
A
B
C
D
LEGEND
FENCE
BERM
WELLS A-D
SURFACE SAMPLING
CROSS-SECTION
ACTIVE AREA
ACCESS ROAD
SAND
COARSE GRAVEL
CLAY
SOIL SAMPLES
WATER LEVEL
OIL/SAND
NOT TO SCALE

FIGURE 12. WELL LOGS - CASE STUDY SITE A.

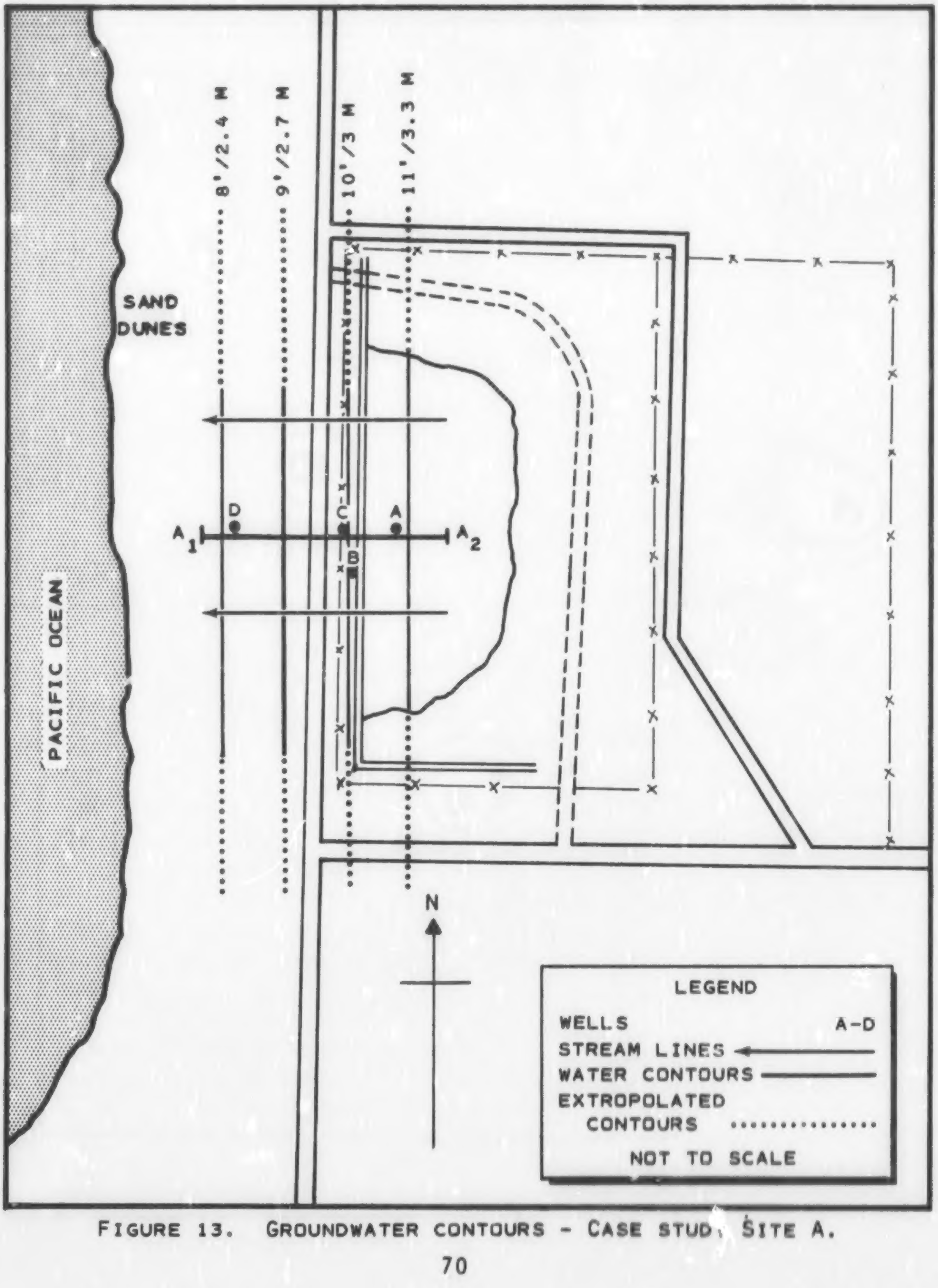

8'/2.4 M
9'/2.7 M
10'/3 M
11'/3.3 M
SAND DUNES
PACIFIC OCEAN
D
C
A
B
A_1
A_2
N
LEGEND
WELLS A-D
STREAM LINES
WATER CONTOURS
EXTROPOLATED CONTOURS
NOT TO SCALE

FIGURE 13. GROUNDWATER CONTOURS - CASE STUDY SITE A.

readings of this water show a TDS value of 25,000 ppm attesting to probable salt water intrusion when hydraulic gradients permit.

Surface Water

The site surface hydrology consists of limited runoff in a westerly direction during periods of intense precipitation. High permeability of the sandy surface soils and relatively flat topography suggest that minimal runoff occurs from the site.

Oily Wastes Received

Since 1959, Site A has received various types of oily wastes from the 15 oil companies active in the area. Drilling muds have constituted the largest portion. Oil content in the drilling muds was historically about 10 percent. Recently, the oil content has decreased to about 5 to 7 percent. Most of the oils within these mixtures have been crudes, although specific origins and oil types are nearly impossible to define qualitatively.

Most of the oily wastes presently received at the site are drilling muds and oil and water mixtures derived from oil storage tank bottoms. Some oil spill debris from the Santa Barbara oil spill of 1969 was also accepted at the site, although the specific quantities or locations of deposition are unknown.

Records of waste type and volume received have been maintained as required by the State of California Regional Water Quality Control Board, Los Angeles. According to these records, daily amounts received have ranged from 2.3 to 168 m^3 (15 to 1,059 bbls) of oily waste per day. Recently, land cultivated quantities have been approximately 3,200 m^3 (20,000 bbls) of oily waste per month.

Operating History and Disposal Procedures

In 1954, 12 ha (30 ac) of beach land were leased to a private contractor for use as an oily waste disposal site. This original plot was utilized as an oil sump where oily wastes were lagooned until 1959. After that, land cultivation operations began, and the material was mixed with indigenous sands. In 1959, another 14 ha (35 ac) directly west of the original property was leased. Various sections of this land have been used for land cultivation since this time. The original contractor is still active at the site.

Land Cultivation Procedures

The procedures used at Site A have evolved by trial-and-error over its 22-yr operating history. Site maintenance plays an important role in the land cultivation operation. All active areas of the site are maintained level so that ponding and runoff are minimized. The access road used by waste delivery trucks is graded and maintained in good condition. Slopes from this road to the active area are maintained at about 10 percent minimum, so that the oily wastes can flow by gravity from the trucks onto the level active area (see Figure 14).

After deposition in the working area, a track dozer mixes the oily waste with sand and previously deposited oil waste to promote aeration and contact with oil-consuming bacteria. Figure 15 shows the track dozer used and a recently mixed plot. The dozer operator mixes the oily material with the sandy soil by the combined action of pushing with the blade and churning up the soil with the track. Several passes over the plot are usually sufficient for thorough mixing. A disc harrow is used less than five percent of the time. Under prevailing conditions, the blade provides sufficient mixing. Mixing continues under most weather conditions. Only in periods of heavy rain is the mixing halted.

The dozer operator constitutes the only full-time employee at the site. Traffic control is unnecessary since vacuum trucks arrive infrequently throughout the day.

Monitoring the operation for environmental safety is accomplished by the California Regional Water Quality Control Board, Los Angeles. This agency also maintains monthly records of the volume and origin of the deposited wastes. Review of this agency's field notes and discussions with field investigators indicate only a few minor difficulties have been noted during the 22 years of operation.

Several informal discussions with the site operator indicated that he was confident of the effectiveness of this system of oily waste disposal. The loose sand which previously occupied the site has been transformed into a dark, silty-sand soil. This is due in part to the large volume of waste muds brought into the site from drilling operations. The soil is noticeably more consolidated and seems to support plant life where dozer activity does not interfere. Surficial soil in areas where land cultivation has not occurred in several years appeared unoiled and had no hydrocarbon odor.

No overall cost information is available. The operator did indicate that discing of the soil/oil mixture is more costly than normal dozer operations due to increased equipment wear. The oil-sand mixture presents significant opportunities for abrasion of all moving parts since the oily sand tends to stick and act as a grinding compound.

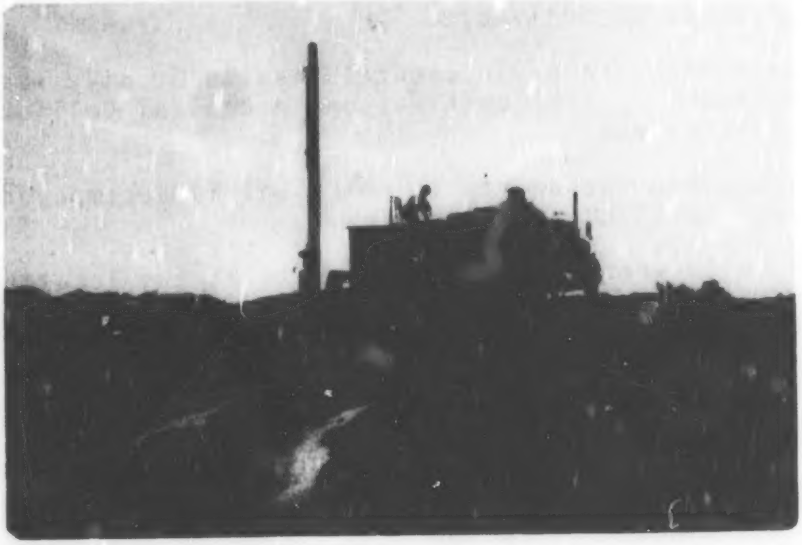


FIGURE 14. OILY WASTES DEPOSITED AT SITE A.

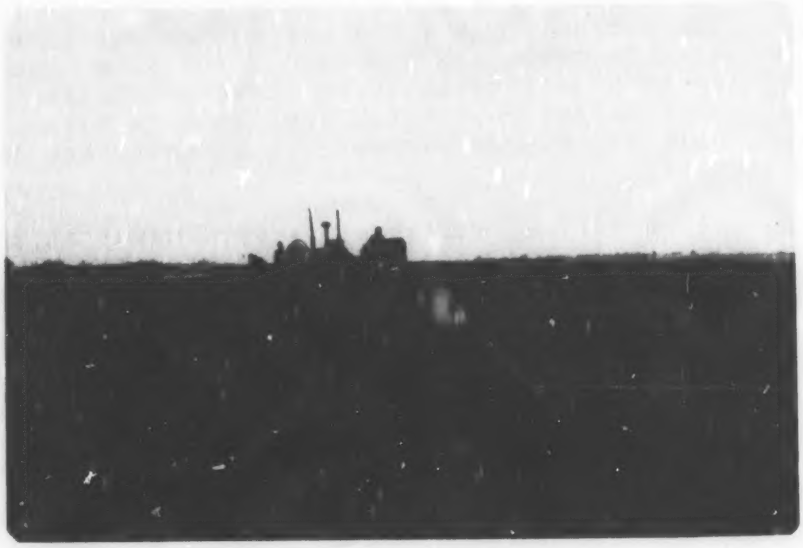


FIGURE 15. MIXING OF OILY WASTES AND SANDS, CASE STUDY SITE A.

Case Study Monitoring

A monitoring program was devised for the Oxnard site to attain two basic objectives:

- Determine the environmental impacts of oily waste disposal by land cultivation in coastal California's climate; and
- Determine the degree to which oil is decomposed by the land cultivation activities.

Four wells were drilled at the site at the locations and to the depths noted on Figure 12.

- One well (Well A) within the active area;
- One well (Well B) in a recently active, but now idle area; and
- Two wells (Wells C and D) off-site and downgradient from the other wells.

The wells were placed to ensure that any downward percolation of oily material would be detected by sampling the underlying soils and groundwater. Well B was placed in an area that had not been mixed for approximately three years.

All wells were drilled with a 15 cm (6 in) auger to the depths shown in Figure 12. They were then cased with PVC pipe and capped. The bottom 0.9 m (3 ft) of casing was grooved to allow groundwater to pass into the casing for water sampling. Water levels in each well remained relatively constant throughout the day of installation. Water samples were taken from each well for analysis of several parameters, as described in the following section.

During well drilling, soil samples were taken at several intervals, as shown on Figure 12 following procedures outlined in Appendix A to this Volume II.

Soil materials encountered during drilling were uniform, indicating the relative homogeneity of the subsurface regimen. All samples of soil were packed in ice and returned to the laboratory for analysis. Once per week for the following five weeks, a sample of soil/oil mixture was taken for analysis from or just below the surface. The sampling point was approximately 4.5 m (15 ft) south of Well A.

Analytical Results

Tables 10 and 11 present the results of the various analyses performed on oily soil and groundwater samples obtained from Site A. Data on Table 10 pertains to samples taken on March 19, 1976. Table 11 presents data on subsequent surface soil/oil samples. The laboratory analytical techniques used to determine this data are described in Appendix B. Note that all samples were not necessarily analyzed for all parameters.

Data Evaluation--

Review of the analytical results in Tables 10 and 11 indicate that oil may be migrating from the upper layers of the land cultivation area to the perched water below. However, the data is not extensive enough to prove that the land cultivation site itself is the only source of detached oil. Nor can the areal limits of oil migration be defined.

The concentrations of oil in soil samples taken from all four wells range from less than 0.1 mg per g (at different depths in Wells A, B, and C) to 34.2 mg per g at 1.5 m (5 ft) deep in Well A. Although there are many anomalies, the overall trend shows the oil content of soil samples decreasing with depth in each well. Yet the oil content of soil samples as deep as 9.4 m (31 ft) were relatively high: 0.26 mg per g (or 260 ppm).

All water samples contained relatively high oil contents: from 7.16 mg/ℓ at Well D to 36.8 mg/ℓ in Well A. This suggests that oily material is reaching the perched groundwater, although the oil source may or may not be from the land cultivation site. Analyses of upstream groundwater were not available for comparison, however. (Seawater intrusion likely affects the perched water further inland than the site, so background water may also contain oil from the site.) The relative proportion of paraffinic, aromatic, and polar oil fractions for oil taken from water samples are close to those fractions of soil samples.

Oil may have entered the groundwater by downward migration through the sand, or it could have been leached from the upper soil profile during periods of high seawater intrusion, when the groundwater elevations are near the surface. Also, oil exploration and storage in the vicinity could contribute some of the oil detected in the groundwater sampled.

Analyses of the samples of land cultivated oily waste and soil mixtures obtained at one-week intervals for five weeks show a slight trend toward reducing oil content with time (Table 11). The sampling period was not of sufficient duration to show the definite long-term effects of oil degradation, however. Also, it is difficult to obtain consistent representative samples from a land cultivation site since the soil/oil mixture is

TABLE 10. RESULTS OF SOIL AND WATER SAMPLE ANALYSES

WELLS A, B, C, AND D - CASE STUDY SITE A

Well/ Sample No.	Type of Sample	Depth of Sample		Moisture Content % by wt.	Organic Acid	Total Organic Nitrogen	PO_4	Pb	Fe	Aerobic	Anaerobic	Yeast & Mold
		m	ft		ppm					Plate Count (1000's)		
A 1	Soil	surface			75	834.0	2053	3.0	6900	900	0.65	0.01
2	Soil	0.9	3	11.6	570	552.0	949	4.2	1395	2700	72.0	15.00
3	Soil	1.5	5	12.1	420	703.0	1151	3.0	3360	1800	3.0	2.60
4	Soil	3.6	12	3.3	60	115.0	1289	2.4	3400	3800	150.0	0.13
5	Soil	4.8	16	10.7	990	116.3	1275	5.2	2025	2500	90.0	0.12
6	Soil	6.9	20	22.1	60	46.2	1449	1.0	3550	900	8.5	0.03
7	Soil	9.4	31	19.6	60	42.7	375	4.0	3900	330	0.5	0.04
8	Water	3.3	11	--	20	36.4	1	0.8	252.5	864	1.2	0.02
B 1	Soil	surface		--	--	--	--	--	--	--	--	--
2	Soil	2.4	8	--	--	--	--	--	--	--	--	--
3	Water	3.0	10	--	70	294.0	9	0.7	100	240	0.25	0
C 1	Soil	1.0	3	5.1	30	43.4	1458	3.0	2500	360	10.0	0.90
2	Soil	2.1	7	16.4	2304	72.2	249	5.8	3538	660	14.0	1.40
3	Soil	3.0	10	16.8	180	40.6	1824	1.6	3025	300	2.0	0.25
4	Soil	4.5	15	16.9	582	39.2	645	3.0	2835	240	1.0	1.46
5	Soil	5.7	19	16.4	330	48.3	116	3.6	3135	150	0.04	0.03
6	Water	2.7	9	--	270	359.0	0	1.0	222.5	150	0.3	0.40
D 1	Soil	1.0	3	17.2	420	33.9	1919	5.0	4375	600	60.0	0.02
2	Soil	4.2	14	3.9	60	76.2	1437	2.4	4900	4500	6.0	0.03
3	Water	2.4	8	--	69	26.6	0	0.7	226.5	100	0.5	0.18

TABLE 10 (continued)

Well/ Sample No.	Type of Sample	Depth of Sample		Parameter				
		m	ft	Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
						Paraffin	Aromatic	Polar
A 1	Soil	surface		39.1	32.8	29.7	12.2	57.9
2	Soil	0.9	3	--	--	--	--	--
3	Soil	1.5	5	41.1	34.2	27.6	1.3	59.3
4	Soil	3.6	12	3.0	3.0	26.3	13.1	60.5
5	Soil	4.8	16	0.1	0.1	13.7	2.2	84.0
6	Soil	6.9	20	3.7	3.6	28.9	12.2	58.7
7	Soil	9.4	31	0.3	0.3	24.2	7.8	67.9
8	Water	3.3	11	59.0 mg/l	36.8 mg/l	24.9	10.0	64.1
B 1	Soil	surface		39.1	32.8	29.7	12.2	57.9
2	Soil	2.4	8	0.1	0.1	17.3	6.6	76.0
3	Water	3.0	10	53.0 mg/l	23.4 mg/l	22.1	7.7	70.1
C 1	Soil	1.0	3	0.2	0.1	7.6	6.2	86.0
2	Soil	2.1	7	0.2	0.1	27.2	2.0	51.9
3	Soil	3.0	10	--	--	--	--	--
4	Soil	4.5	15	51.8	37.1	33.9	9.9	56.2
5	Soil	5.7	19	0.2	0.1	20.0	12.9	66.8
6	Water	2.7	9	44.8 mg/l	19.8 mg/l	14.1	5.5	80.0
D 1	Soil	1.0	3	0.6	0.2	14.7	17.4	67.8
2	Soil	4.2	14	51.8	37.1	33.4	9.7	56.2
3	Water	2.4	8	27.2 mg/l	7.2 mg/l	15.5	3.3	81.1

TABLE 11. RESULTS OF SURFACE SOIL/OIL SAMPLE ANALYSES - CASE STUDY SITE A

Date of Sampling	Parameter				
	Total Extractable Hydrocarbon, mg/g	Oil Content, mg/g	Oil Fraction, Percent		
			Paraffin	Aromatic	Polar
3/19/76	39.1	32.8	29.7	12.2	57.9
4/7/76	42.0	30.7	27.5	9.5	62.9
4/19/76	31.4	27.2	31.5	10.8	57.6
4/21/76	29.0	26.3	26.3	11.7	61.8
5/5/76	34.5	31.6	27.6	11.2	61.1

usually not homogeneous. Errors in later sampling may be reduced by using cone and quartering techniques developed in the mineral mining industry to obtain samples for assays.

Conclusions and Recommendations for Further Studies--

Evidence suggests that oil may be escaping the site through the porous sandy soils. Most of the oil received apparently remains at or near the land surface where it apparently degrades within one year, according to the site operator.

Useful data on oil degradation rates could be obtained by continued sampling of the soil/oil mixture at a designated location at the site. Cone and quartering techniques should be employed to obtain statistically representative samples over a period of 8 months to one year.

Drilling of at least one other well off-site to the east of the site could help define the extent of lateral migration due to seawater intrusion. Also, the quality of the perched groundwater away from the site should be determined by drilling a well further inland away from the site's possible area of influence.

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2. Climatological Data. California Annual Summary, 78(13). U.S. Dept. of Commerce, Rational Oceanic and Atmospheric Administration, Environmental Data Service, 1974.

3. Sea-Water Intrusion in California, Geologic Map of California. Dept. of Water Resources, No. 66, Division of Mines and Geology, 1969.

SECTION 2 - CASE STUDY SITE B, LITTLE MOUNTAIN, UTAH

Background

In 1972, leakage in the dike of a waste oil lagoon near Little Mountain, Utah, resulted in the out-flow of oily waste and contaminated water onto a neighboring state bird refuge. The U.S. Environmental Protection Agency (EPA) declared the site an imminent and substantial hazard in October, 1973, after the landowner failed to take the necessary actions to control the oily waste leak.

EPA contractors began cleanup operations at the site in May, 1974. The upper layer liquid phase was collected by tank truck and disposed of by landspreading at a site on Hill Air Force Base property located near the leaking sump. Sludges at the sump were mixed with local fine-grained soil and covered with a soil cap.

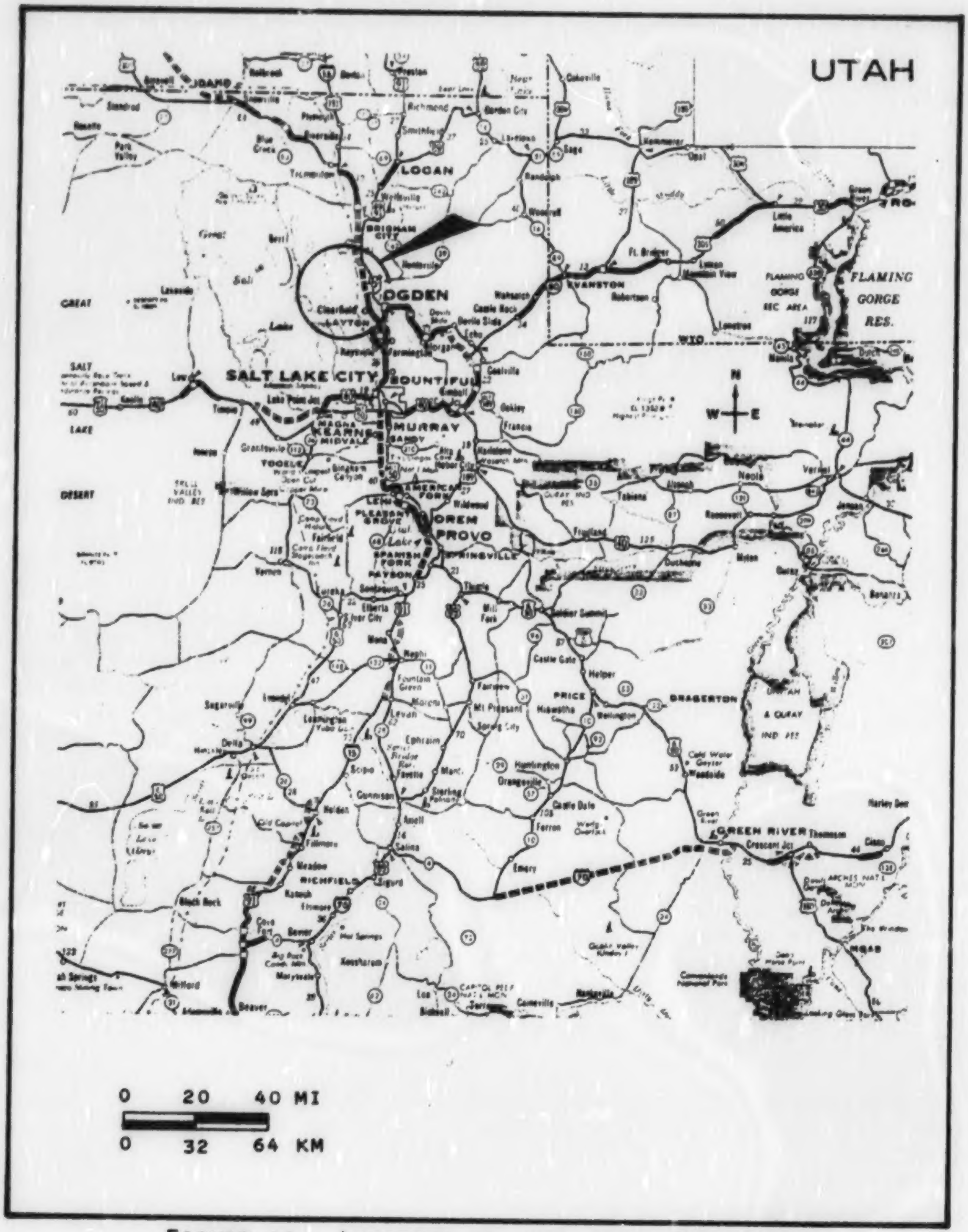
The land cultivation disposal operation is the subject of the case study. Both cleanup operations are fully described in the On-Scene Coordinators report, presently in preparation by EPA Region VIII representatives in Denver, Colorado.

Site B was selected to represent an oil spill debris disposal land cultivation operation in a cold, dry climate. Also, much of the disposal operations were closely supervised by EPA personnel and the site has been periodically monitored by an EPA contractor, Dr. John Skujins, Professor of Biology, Utah State University, Logan, Utah. The monitoring program implemented during this case study was thus developed to complement available analytical data (1, 2).

Little Mountain, Utah, is located approximately 65 km (40 mi) northwest of Salt Lake City and several miles due west of Ogden, as shown on Figure 16. Case study Site B lies within 1.6 km (1 mi) of the eastern shore of the Great Salt Lake, as shown on the aerial photograph, Figure 17. A dirt road to a Hill Air Force Base facility north of the site provides access. Remnants of access roads constructed during oily waste disposal operations are still visible (Figure 17). Figure 18 shows a plan view of the various plots that received oily waste during land cultivation.

Topographically, the site lies near the toe of a small mountain. Relief is characterized by numerous shale outcroppings. The surface slopes at less than 5 percent on site (Figure 19).

Land in the area of Site B is mostly vacant. Some structures are present to serve the Air Force, and a Great Salt Lake Company


UTAH
LOGAN
BRIGHAM CITY
OGDEN
LAYTON
EVANSTON
FLAMING GORGE RES.
SALT LAKE CITY
BOUNTIFUL
MURRAY
KEARNS
MIDVALE
MAGNA
TOOELE
AMERICAN FORK
OREM
PROVO
SPANISH FORK
SPRINGVILLE
PAYSON
PRICE
DRAGERTON
UINTAH & OURAY IND RES
GREEN RIVER
RICHFIELD
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0 20 40 MI
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FIGURE 16. LOCATION OF CASE STUDY SITE B - LITTLE MOUNTAIN, UTAH.

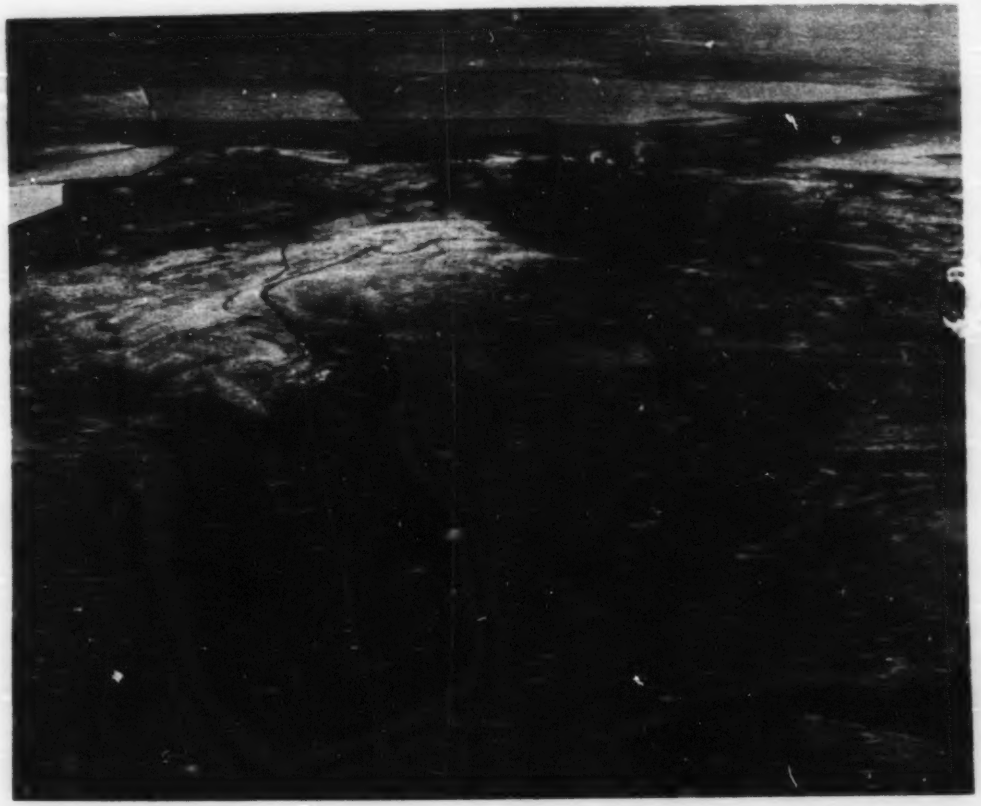
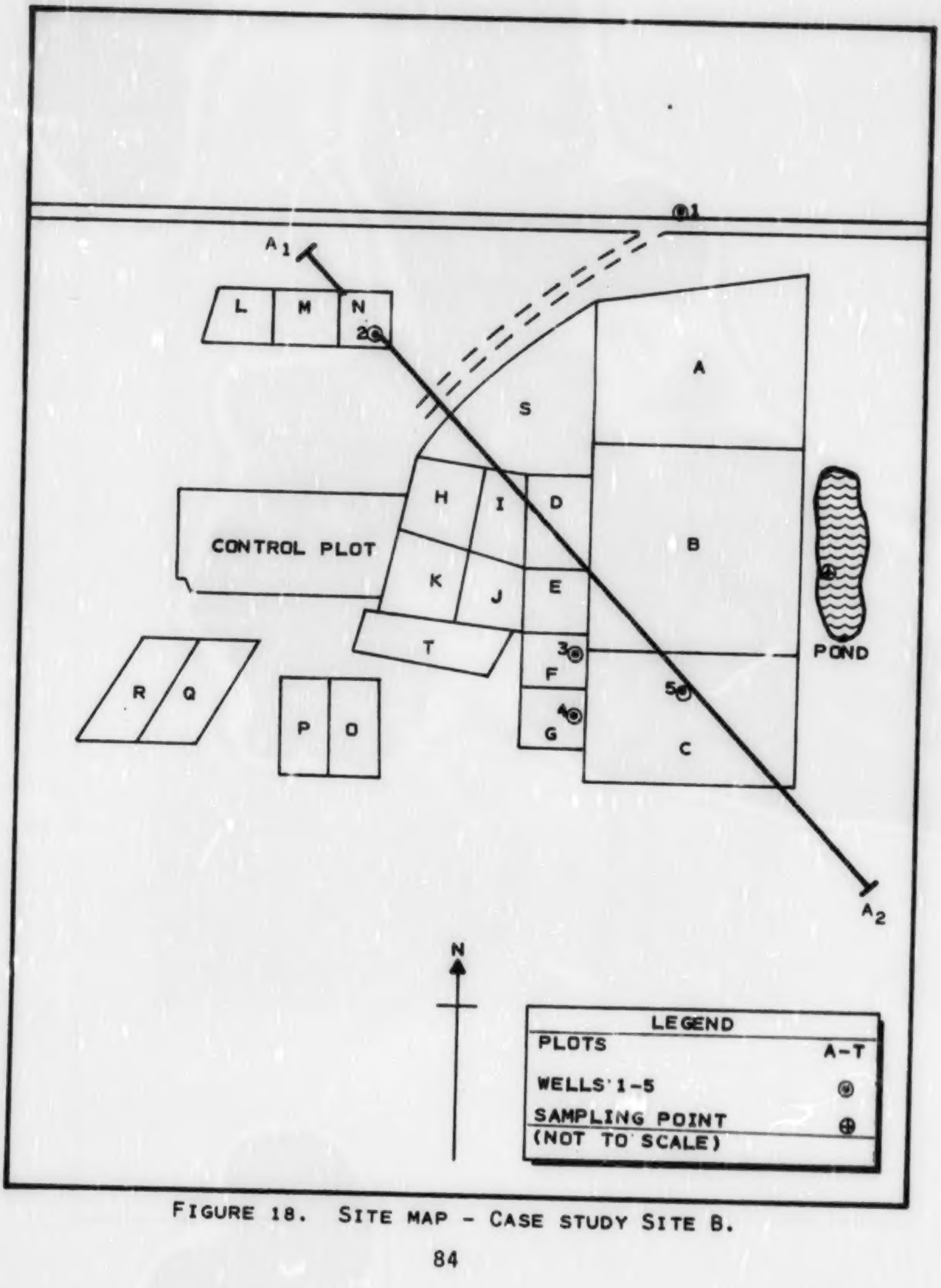


FIGURE 17. OBLIQUE AERIAL PHOTO OF CASE STUDY SITE B - OCTOBER 20, 1975 (NORTH TOWARDS TOP OF PAGE).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4
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C
A2
N
LEGEND
PLOTS A-T
WELLS 1-5
SAMPLING POINT
(NOT TO SCALE)

FIGURE 18. SITE MAP - CASE STUDY SITE B.

FIGURE 19. LAND CULTIVATED SURFACE TWO YEARS AFTER OIL APPLICATION - CASE STUDY SITE B.

mineral recovery plant is located nearby. A railroad borders the land disposal area on the south.

Natural vegetation in the area is sparse, consisting of cheat grass and wild sunflowers. This site was classified as unfit even for range pasture, although private lands to the east of the site are used for sheep and cattle pasture and some agriculture.

Climate

Pertinent climatological data for the Little Mountain area is summarized on Table 12. Winds vary in direction but are usually light to moderate, ranging normally below 32 kph (20 mph). Recorded temperatures vary from lows of -3°C (26°F) to 24°C (75°F). Annual precipitation averages 43.3 cm (17.1 in) (1).

Geology and Soils

Available data indicate that the soils encountered during drilling were representative of the Barton rocky loam series. A composite soil profile based upon sieve analysis of samples taken from test borings on April 20, 1976, is illustrated in Figure 20. This soil apparently ranges in depth from several feet in the northern extremity to approximately 3.0 m (10 ft) in the southern portion of the site. Underlying this loam was a very cobbly and stony layer of approximately 0.9 m (3 ft) deep derived from massive tillite to the east. Approximately 50 to 80 percent of the soil mass consisted of cobbles and stones. Beneath the cobbly substrate is a dark brown shale shown on Figure 21. Numerous shale outcrops are visible on-site. While the shale was near surface in several areas of the site, drilling locations were selected to avoid such areas. This dense shale exhibited a nearly vertical dip in the on-site outcrops (2).

Groundwater

Available information and well observations on April 20, 1976, indicate that no shallow groundwater system exists below the site. This is due to several factors including the dense underlying shale, high sorptive soil capacities, and the relatively arid climate. The small amount of precipitation which does occur is readily absorbed by the dry soil. The high absorption property of the dry soils also minimizes any subsurface movement. It is expected that surface runoff is minimal as well.

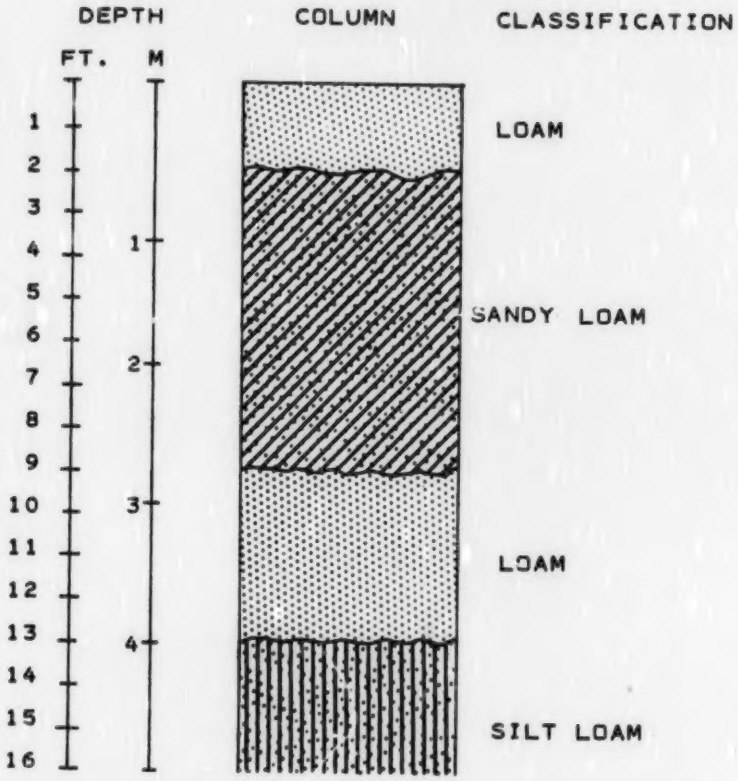
No water was encountered in any of the observation wells on April 20, 1976. Ponded water was observed at an abandoned quarry on the eastern boundary of the site. The elevation of the water

TABLE 12. SUMMARY OF CLIMATOLOGICAL DATA - CASE STUDY SITE B

Month	Average Monthly Temperature*		Precipitation (annual)*		Evaporation+	
	°F	°C	in	cm	in	cm
Jan.	26.2	-3	1.7	4.3	--	--
Feb.	31.5	0	1.5	3.7	--	--
March	39.5	4	1.6	4.0	--	--
April	50.0	10	2.2	5.5	--	--
May	58.5	14	1.6	3.9	6.7	16.9
June	66.0	19	1.3	3.3	8.2	20.7
July	75.4	24	0.6	1.4	9.9	25.0
Aug.	73.4	23	0.8	2.0	8.8	22.3
Sept.	64.2	18	0.8	2.1	6.0	15.2
Oct.	53.0	12	1.7	4.2	--	--
Nov.	38.7	3	1.6	4.2	--	--
Dec.	31.3	0	1.8	4.6	--	--
Annual	50.6	10	17.2	43.2	39.6	100.1

* Based upon 1931-1960 data.

+ Based upon 1975 data.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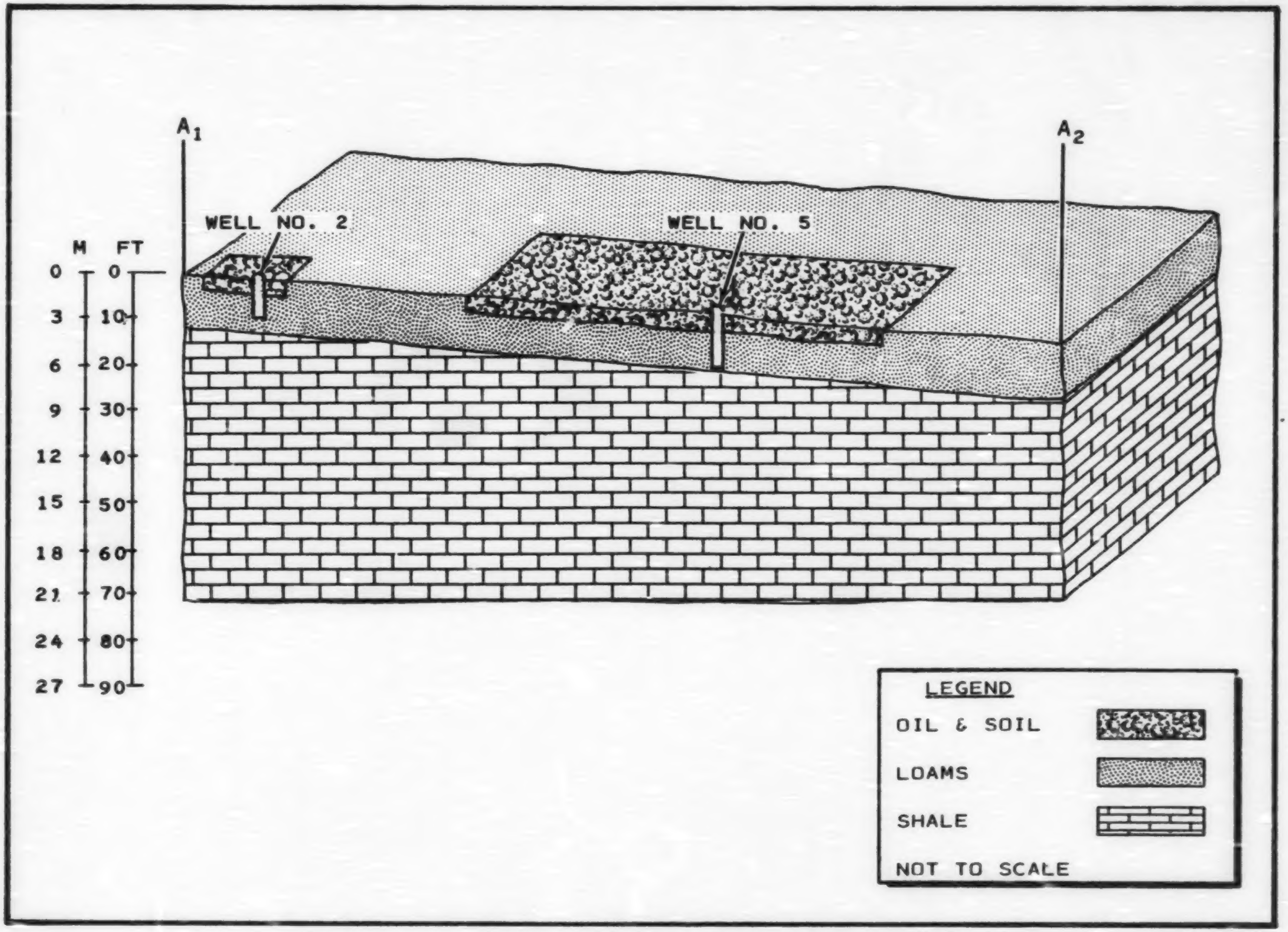
LOAM
SANDY LOAM
LOAM
SILT LOAM

FIGURE 20. SOIL PROFILE BASED UPON SIEVE ANALYSIS - CASE STUDY SITE B.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WELL NO. 2
WELL NO. 5
LEGEND
OIL & SOIL
LOAMS
SHALE
NOT TO SCALE

FIGURE 21. CROSS-SECTION - CASE STUDY SITE B.

surface in the quarry is approximately 15 to 18 m (50 to 60 ft) lower than the Site B surface.

Surface Water

No permanent surface water is present at the site. Drainage channels and other surface manifestations of waters are also absent.

Oil Spill Debris Disposal

For many years, waste crankcase oil, acid sludge, spent filter cake, and train engine journal box oil were deposited in the privately owned and operated Little Mountain waste oil sump. In 1972, the sump was filled to capacity and closed. The operators took no further actions after site closure to remove accumulated oil or auto bodies from an adjoining scrap yard that had become mixed with the oily waste. Sump dikes were not reinforced.

Subsequently, an overflow and seepage break in the dike occurred on the southwest corner causing the entrapped water and oil/water emulsion to flow out of the sump onto neighboring state bird refuge land. Due to these conditions, the U.S. Environmental Protection Agency declared the site an imminent and substantial hazard in October, 1973. After landowners and site operators failed to take necessary corrective action, personnel from the Oil and Hazardous Materials Emergency Planning and Response Branch, Surveillance and Analysis Division, EPA Region VIII, began planning cleanup and sump closure procedures in February, 1974.

In March, 1974, approval was obtained to use special federal funds set aside for emergency spill cleanup activities to finance this cleanup effort. EPA contractors thereafter began executing oil cleanup and disposal operations. Dr. John Skujins was retained by EPA to assist in the development of cleanup and disposal plans.

Three basic types of oily waste material were present, and each required disposal:

- Waste acid sludge from an Ogden oil re-refinery;
- Acid water and oil emulsion;
- Acid water with minor oil contamination.

EPA's disposal plan called for removal of the liquid fraction to nearby land on Hill Air Force Base property, 3.2 km (2 mi) west of the sump. There the contaminated water and oil emulsion was land cultivated to facilitate aerobic decomposition of the oil fraction. (A small amount of acid sludge was also removed for cultivation. However, most of the sludge was handled at the sump site itself. The sludge was mixed with silty soil imported from a nearby borrow pit after the liquid fraction was removed by tank truck.)

While the primary purpose of this operation was to effectively dispose of the liquid oily waste, Dr. George Rice of EPA and Dr. Skujins took the opportunity to devise a concurrent limited land cultivation research program. The site was subdivided into 21 plots (including one control plot), and varying concentrations of oily waste and fertilizer were applied to each plot. Figure 18 shows the location of each plot.

Prior to cultivation, the treatment plots were prepared by scarifying, removing the rocks, discing, and tilling. Lime and fertilizers (urea and phosphates) were applied to the native soils to neutralize the acidic emulsion and to provide nutrients for bacteriological decomposition. (Values of pH for the untreated emulsion ranged from 1.0 to 2.0.) The soil and admixtures were then tilled to a depth of approximately 21 cm (5 in). The liquid material was spread by tractors on the scarified plots and mixed with the soil by discing to assure adequate aeration and soil-oil mixture.

Most of the cultivated materials consisted of oil and water emulsions amounting to approximately 4,500 m^3 (1.2 million gal). Of that, a total of 2,800 m^3 (750,000 gal) were emulsion that was deposited on 14 separate plots designated A through N (Figure 18). The other waste was acid water only slightly contaminated with oil which was spread on plots O through R. Oil stained soil and sludge amounting to approximately 481 m^3 (630 cu yd) was deposited in plot T. Table 13 indicates the application rates for oily waste and additives for each plot (3).

Dr. Skujins was retained by EPA to monitor the cultivated plots for 18 months. Dr. Skujins sampled surface soil and oil emulsion mixtures at various times during and after the land cultivation activities, as follows:

- June 6, 1974;
- August 2, 1974;
- November 7, 1974;
- March 10, 1975;
- April 22, 1975;
- May 20, 1975;
- June 27, 1975;
- July 16, 1975;
- September 12, 1975;
- April 20, 1976.

TABLE 13. APPLICATION RATES OF MATERIALS ADDED TO PLOTS - SITE B, LITTLE MOUNTAIN, UTAH(3)

Plot	Acres	Oily Waste (in 1000 gal/ac)		Lime (lbs/acre)	Phosphorus (20%) (lbs/acre)	Nitrogen (45%) (lbs/acre)	Depth of mix (inches)
		Emulsion	Aqueous*				
A	6.90	16.0	2.7	800	250	830	5
B	10.97	19.7	1.6	930	250	830	5
C	8.04	14.3	2.0	935	250	830	5
D	0.73	23.0	11.1	935	250	830	5
E	0.96	23.0	11.1	935	500	1,660	5
F	0.87	25.7	14.9	1,680	750	2,490	5
G	0.91	25.7	14.9	1,660	250	830	5
H	1.08	23.9	14.6	1,900	500	1,660	5
I	0.96	23.9	14.6	1,900	500	1,660	5
J	1.20	23.9	14.6	1,900	750	2,490	5
K	1.02	23.9	14.6	1,900	750	2,490	5
L	0.94	19.5	13.5	1,670	750	2,490	5
M	0.84	19.5	13.5	1,670	500	1,660	5
N	0.84	19.5	13.5	1,670	250	830	5
S	4.20	9.8	11.0	-	-	-	5
T**	0.99	-	-	-	-	-	5
O,P Q,R	4.40	-	150.8	-	-	-	3
Dust Control	-	-	47.8	-	-	-	-

Note: 1 gal/ac = 7.36 ℓ/ha and 1 lb/ac = 1.12 kg/ha

* One bag of lime for pH control was added to each truckload of aqueous solution as it was pumped from the lagoon. Approximate ratio - 50 pounds lime: 7,000 gallons aqueous.

**Contains approximately 630 cubic yards of oil-stained soil stripped from exposed surfaces of lagoon bottom.

Table 14 shows the extensive list of parameters analyzed by Dr. Skujins. Results of the 1974 and 1975 analyses are reported in annual reports to EPA (2, 3).

In April, 1975, the fertilized plots were cultivated for the second time. Also, more fertilizer was added to previously fertilized plots. Subsequently, evaluation of the monitoring results showed that no environmental problems have occurred. Furthermore, the oil content in the plots has steadily decreased. Consequently, the land cultivation disposal operations were declared complete in October, 1975. The area was tilled and seeded, and temporary access roads were removed.

EPA plans to continue periodic monitoring at Site B to ensure that environmental conditions remain acceptable. In addition, the State of Utah Health Department has monitored the ponded water for certain constituents since landspreading activities began. No significant change in water quality has been reported.

Case Study Monitoring

A limited monitoring program was devised for the Little Mountain case study site aimed toward developing data not yet obtained during previous work.

The monitoring program proposed will entail the taking of various soil, soil/oil, and water samples and subsequent analyses thereof. Specifically, the monitoring undertaken during this case study provides information about the extent of oil migration into the soil (below about 12 cm), if any. To a limited degree, some results of this work can be compared with corresponding data developed by Dr. Skujins to check analytical consistency.

A total of five wells were drilled and cased on April 20, 1976, at Site B. The location and depths of these wells (designated Wells 1 through 5) are shown on Figure 22.

Well placement was selected so that plots representing various combinations of nutrient and oil emulsion concentrations were covered. Table 15 indicates the rationale for well location selection. Well locations were discussed with Dr. Skujins to ensure information complementary to his prior and planned work would be obtained. Dr. Skujins was present during well drilling and soil sampling.

All wells were drilled with a 12 cm (5 in) truck-mounted auger, cased with 10 cm (4 in) PVC pipe and capped. The bottom 0.9 m (3 ft) of each pipe was grooved to facilitate infiltration of any subsurface water into the well. As noted previously, however, no subsurface water was found.

TABLE 14. PARAMETERS ANALYZED BY DR. J. SKUJINS DURING MONITORING AT CASE STUDY SITE B

Soil Features

Texture
% Saturation
% Water content
  . at -1/3 atm.
  . at -15 atm.
Oil content
  (ml/gm soil)
Soil respiration
  (μmoles CO_2/g/min)
Microbial composition
  (% by type)

Parameters Reported as %

Kjeld. N
Organic C
P (total)
Lime
Al
Gypsum
Parameters

Reported as Watersol meq/100g

Cl^-
HCO_3^-
Na
K
Ca
Mg

Parameters Reported in ppm

NO_3^-B
Fe
Zn
As
Se
Hg
Co
Pb
Cd
Cu
Mn
Ba
Ni
V
Be
B
P (available)

Calculated Values, in Exch. meq/100g

Na
K
Ca
Mg

Parameters Reported as meq/100g

Cation exchange cap. (CEC)
Na, K, Ca, Mg } (NH_4OA_c extractable)
I

Miscellaneous Parameters

pH
EC_e (mmhos/Cm)
Biological activity
  (mg formazan per 100 ml filtrate)
Aerobic bacteria
  (N/g dry soil)
Anaerobic bacteria
Proteolytic organisms
Carbohydrate utilizers
Lipolytic organisms
Hydrocarbon utilizers
Fungi
Streptomycetes

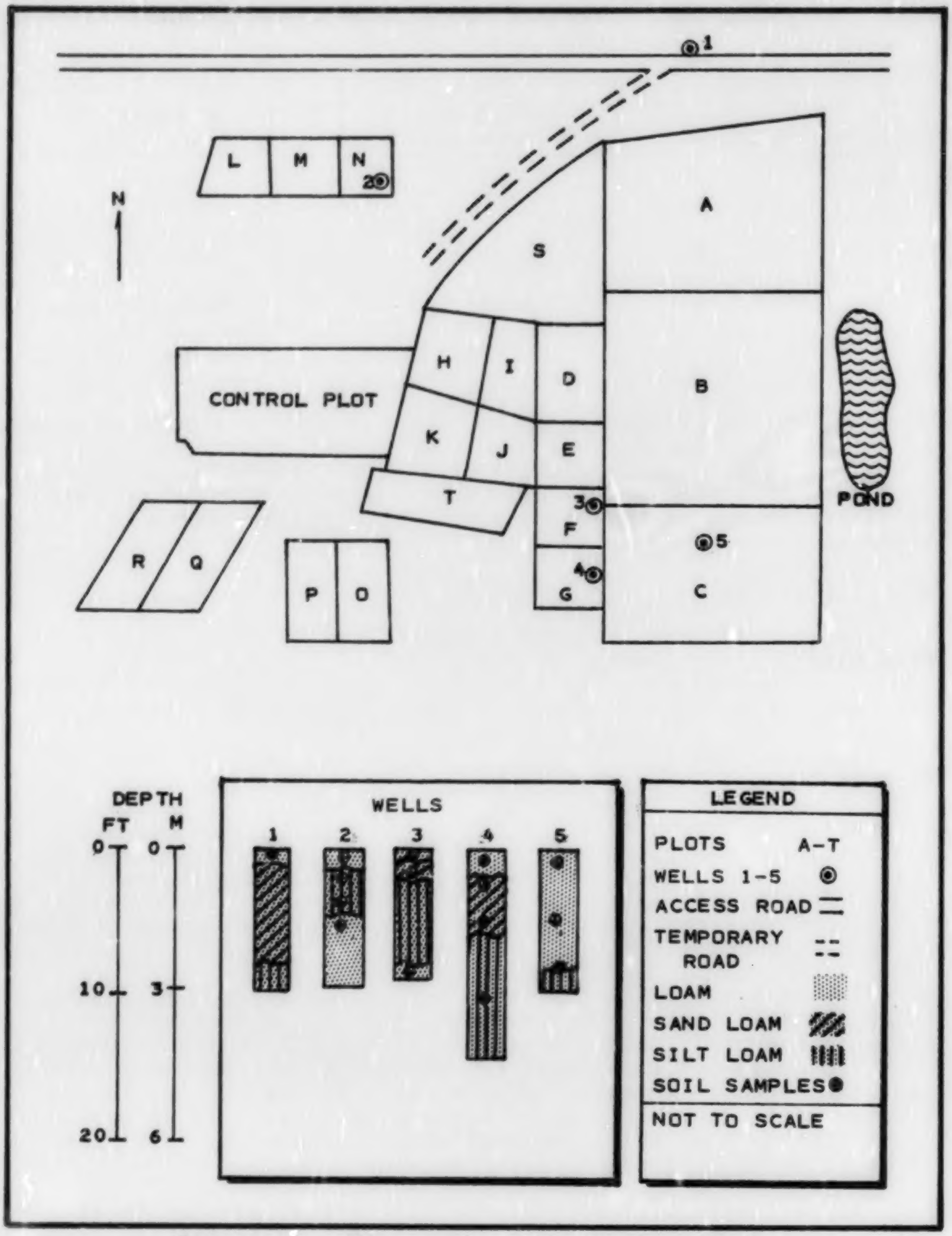
1
L
M
N
2
N
S
A
H
I
D
B
CONTROL PLOT
K
J
E
T
3
F
5
POND
R
Q
4
G
C
P
O
DEPTH
FT
M
0
0
10
3
20
6
WELLS
1
2
3
4
5
LEGEND
PLOTS A–T
WELLS 1–5 ◉
ACCESS ROAD
TEMPORARY ROAD
LOAM
SAND LOAM
SILT LOAM
SOIL SAMPLES ●
NOT TO SCALE

FIGURE 22. WELL LOGS - CASE STUDY SITE B.

TABLE 15. RATIONALE FOR TEST WELL LOCATIONS, CASE STUDY SITE B

Well No.	Plot	Relative Amount of Urea Added	Relative Amount of Emulsion Added
1	Control; No. of A	NA	NA
2	F	Highest	Highest
3	G	Lowest	Highest
4	C	Lowest	Lowest
5	N	Lowest	Low

Soil samples were obtained at several intervals, as shown in Figure 22. The soil samples were relatively uniform between wells indicating a consistent subsurface regimen within the study area.

Data Evaluation--

Results of analyses performed on the soil samples taken from Site B are presented on Table 16. Also shown are the concentrations of selected parameters found in the quarry water. All analyses were performed on samples taken April 20, 1976.

The analyses suggest that little if any vertical infiltration of the oil into the soil has occured. Relatively high oil content values are shown for all surface samples at Wells 2, 3, 4, and 5. Yet the oil content of soils 0.6 to 1.0 m below the surface are lower by a factor of 10 or more. At depths greater than 1.5 m, oil content of the soil is 100 times less than at the surface at the same well location. These results confirm field observations; no visible oil was detected at depths below 12 cm during drilling.

The relative concentrations of paraffinic, aromatic, and polar oil fractions further suggests that no surface oil has migrated downward. Surface samples show a distinctly different combination of fractions than do subsurface soil samples. Also, note that the oil detected in both the off-site control soil sample and in the quarry water contains more than 80 percent polar hydrocarbons while the applied oil apparently is in the range of 59 to 71 percent polar fraction.

Aerobic microbial activity in the surface samples is at least three times greater than subsurface samples for any given

TABLE 16. RESULTS OF SOIL AND WATER SAMPLE ANALYSES

CASE STUDY SITE B -
LITTLE MOUNTAIN, UTAH

Well/ Sample No.	Type of Sample	Depth of Sample m	Depth of Sample ft	Moisture Content % by wt.	Organic Acid	Total Organic Nitrogen	PO_4	Pb	Fe	Cl	Aero-bic	Anae-robic	Yeast & Mold
					ppm						plate count (1000's)		
1 A	Soil	surface		7.9	2	448	25	39.1	26.9	37.2	3680	24	1.2
2 A	Soil/oil	surface		9.7	135	1415	3108	104.5	27.6	21.6	6800	35	7.4
B	Soil	0.6	2	7.6	60	497	2072	38.8	31.9	4.8	490	10	0.6
C	Soil	1.2	4	6.8	50	308	2216	41.1	34.1	15.7	156	<1	0.6
D	Soil	1.8	6	3.1	35	224	2454	43.3	32.3	9.6	30	<1	<0.1
3 A	Soil/oil	surface		11.2	145	1471	2111	152.1	30.0	21.4	704	2	15
B	Soil	1.2	4	4.7	25	806	1218	41.7	34.7	27.0	222	<1	0.5
C	Soil	2.7	9	1.6	15	700	1094	33.1	37.7	24.8	35	<1	0.1
4 A	Soil/oil	surface		11.2	145	1576	1842	129.5	32.5	37.4	7940	11	28
B	Soil	0.9	3	4.8	60	981	1333	53.1	47.1	18.4	2000	4	4
C	Soil	1.5	5	4.0	25	722	1113	22.5	34.3	23.6	35	1	0.2
D	Soil	4.2	14	3.9	40	636	1218	49.7	43.6	19.4	430	<1	2
5 A	Soil/oil	surface		14.8	50	1793	1977	67.4	30.6	16.8	9600	2	3.3
B	Soil	1.0	3	7.1	35	693	815	30.0	28.8	123.0	900	<1	0.3
C	Soil	2.4	8	5.9	15	637	1967	58.8	30.4	212.0	270	<1	<1
Water Sample from Quarry					15	<1	0.12	0.06	0.02	760	1	<<1	<<1

TABLE 16 (continued)

Well/ Sample No.	Depth of Sample		Parameter				
			Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
	m	ft			Paraffin	Aromatic	Polar
1 A	Surface		0.16	0.09	10.9	4.3	84.6
2 A	Surface		16.10	12.40	36.3	4.8	58.8
B	0.6	2	1.25	0.86	30.3	2.6	66.9
C	1.2	4	0.13	0.13	43.2	5.4	51.3
D	1.8	6	2.14	0.94	44.5	3.3	52.3
3 A	Surface		25.80	19.7	26.9	4.1	68.9
B	1.2	4	0.43	0.39	25.8	4.7	69.4
C	2.7	9	0.06	0.05	34.0	6.2	59.3
4 A	Surface		36.90	23.9	24.7	5.4	69.8
B	0.9	3	1.45	1.34	37.6	9.06	53.2
C	1.5	5	0.18	0.11	26.0	6.7	67.2
D	4.2	14	0.31	0.28	38.3	3.1	58.5
5 A	Surface		5.96	5.47	22.7	6.2	70.9
B	1.0	3	0.47	0.47	33.0	2.7	63.7
C	2.4	8	0.03	0.02	28.2	9.4	62.3
Water Sample from Quarry			9.75 mg/l	9.09 mg/l	2.4	2.3	95.2

well. Low moisture content in the subsoil is at least partly the cause of reduced biological activity at these depths. The fact that aerobic bacteria at the surface at Well 1 (control) is about 0.5 of that at the surface at any other well indicates that the oil-degrading bacteria have established themselves in the oiled plots.

Note that the nitrogen and phosphate concentrations are very high for all soil samples, although only Wells 2, 3, 4, and 5 were placed on plots that received area and phosphate application.

Sodium and chloride concentrations show no definite pattern in the oil plots. The high chloride concentration in the quarry pond is likely due to the proximity of salt licks. The reason for the very high sodium value for Well 1A in comparison with all others is not known.

As expected, lead concentrations at the surface in the oil plots are high due to the lead content of the applied emulsion. Background lead is essentially of the same concentration as in subsurface soil samples in the plots.

Conclusions and Recommendations for Further Studies--

Overall, it appears that the oily waste land cultivation disposal project at Site B is not causing environmental problems. The oil concentration is decreasing, according to Dr. Skujins' data, and oil is not migrating away from the immediate region of deposition. Plant uptake of heavy metals has not yet been checked.

This successful operation can be attributable to the careful planning and operation of the land cultivation activity and fortunate availability of a well-suited site. The high sorptive capacity of the tilled soils coupled with the low precipitation and high annual evaporation rates combine to allow microbiological degradation of the oil while impeding its outward migration. Also, volatilization of the lighter oil fractions may help reduce oil concentrations, especially during the summer when evaporation rates are high.

No additional drilling is necessary. It would be beneficial to check each well already drilled for water periodically during and after the wet season. If water is detected, samples should be taken and analyzed for oil content.

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3. Skujins, J. Technical Monitoring of the Oil Disposal Site, Ogden Bay Waste Oil Lagoon Incident. Little Mountain, Utah, Annual Report, 1974. Submitted to U.S. Environmental Protection Agency, Region VIII, Denver, Colorado, January 3, 1975.

4. Skujins, J. Technical Monitoring of the Oil Disposal Site, Ogden Bay Waste Oil Lagoon Incident. Little Mountain, Utah, Annual Report, 1975. Submitted to U.S. Environmental Protection Agency, Region VIII, Denver, Colorado, October 15, 1975.

SECTION 3 - CASE STUDY SITE C, NORTHERN CALIFORNIA

Background

Oil spill debris collected during a beach cleanup on the coast of California north of San Francisco was disposed of in specially excavated trenches in February, 1971. Conditions at Site C are considered representative of typical oil spill debris disposal by burial. A limited monitoring program, including analysis of soil, oil spill debris, and groundwater samples was undertaken to determine the environmental compatibility of this particular disposal method at this location.

The oil spill debris burial trenches are on private property and occupy approximately 0.4 ha (1.0 ac) of land. Access to the trenches from the paved county road is by dirt road. Several structures are clustered about 1.5 km (0.9 mi) to the north of the trenches.

Figure 23 shows a plan view of the disposal site. A total of seven trenches or silos designated by numbers 1 through 7 were excavated. Silos 1 through 6 were completely backfilled with oil spill debris; silo 7 is only partially full.

Site C's topography is defined as a marine terrace area with gently sloping hills rising to the east. Slopes average 5 percent grade. The site contains several canyons between the hills which provide drainage. Six of the disposal silos were excavated into one of these hills on a west-facing slope; these are referred to as the "south silos" on Figure 24. The seventh, partially filled silo (referred to as the "north silo") is on a south-facing slope on the opposite side of the canyon.

Surrounding land is used primarily for agriculture and pasture. Cattle graze at the site and are often seen on and around the debris disposal area itself.

Climate

Climatological data for the Site C area is summarized on Table 17. Prevailing winds are typically easterly throughout the year. Temperatures range from -1° C (30° F) to 35° C (94°F). Mean annual temperature is 13.5° C (56° F).

Geology and Soils

Available records show that Site C lies on a coastal terrace of middle Miocene marine deposits. The soils are part of the Rohnerville series which consist of moderately well-drained loams. The uppermost 0.3 m (1 ft) consists of a silty loam underlaid by about 1 m (3 ft) of yellowish sandy clay loam with

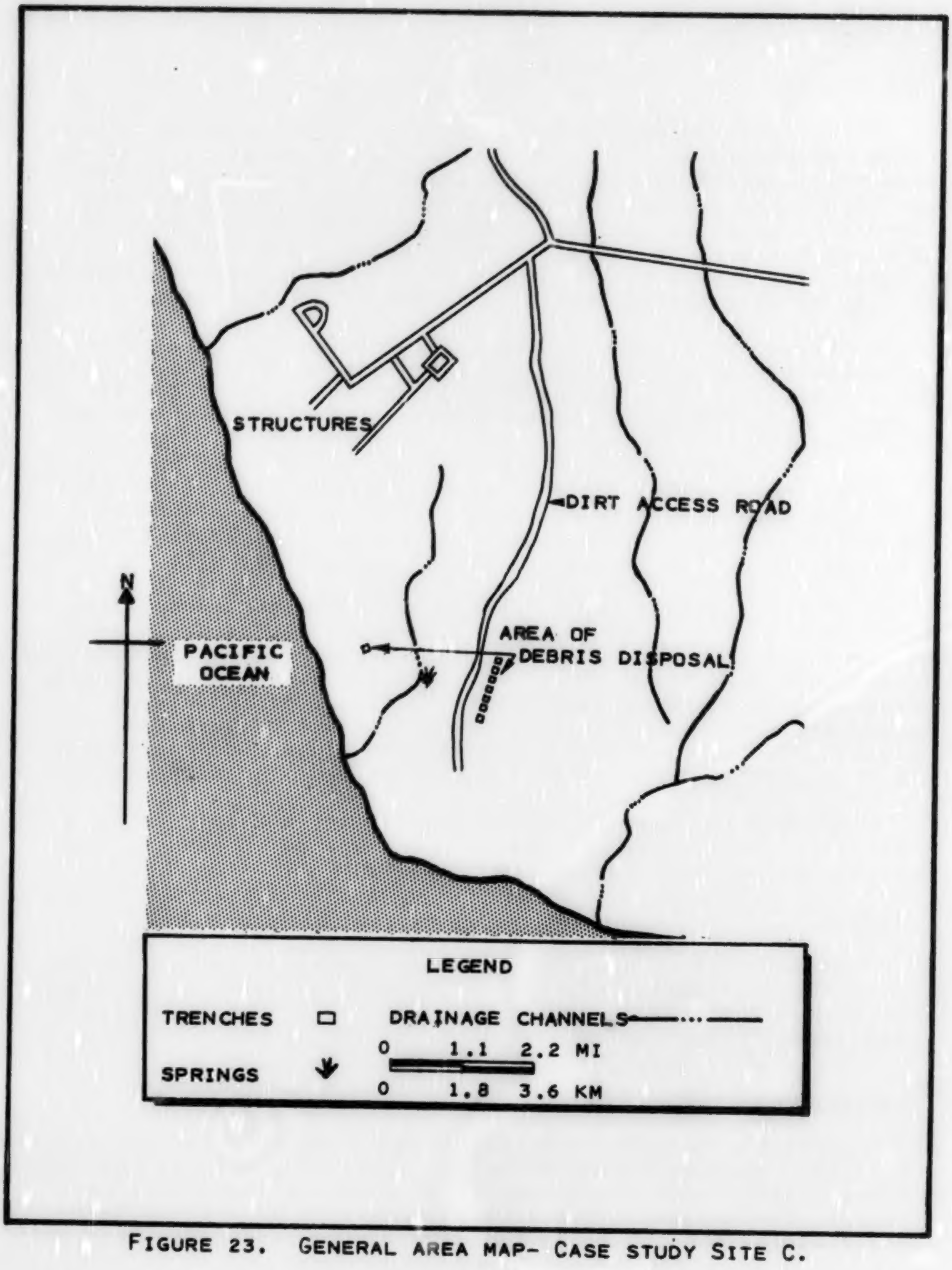
STRUCTURES
DIRT ACCESS ROAD
N
PACIFIC OCEAN
AREA OF DEBRIS DISPOSAL
LEGEND
TRENCHES
DRAINAGE CHANNELS
SPRINGS
0 1.1 2.2 MI
0 1.8 3.6 KM

FIGURE 23. GENERAL AREA MAP- CASE STUDY SITE C.

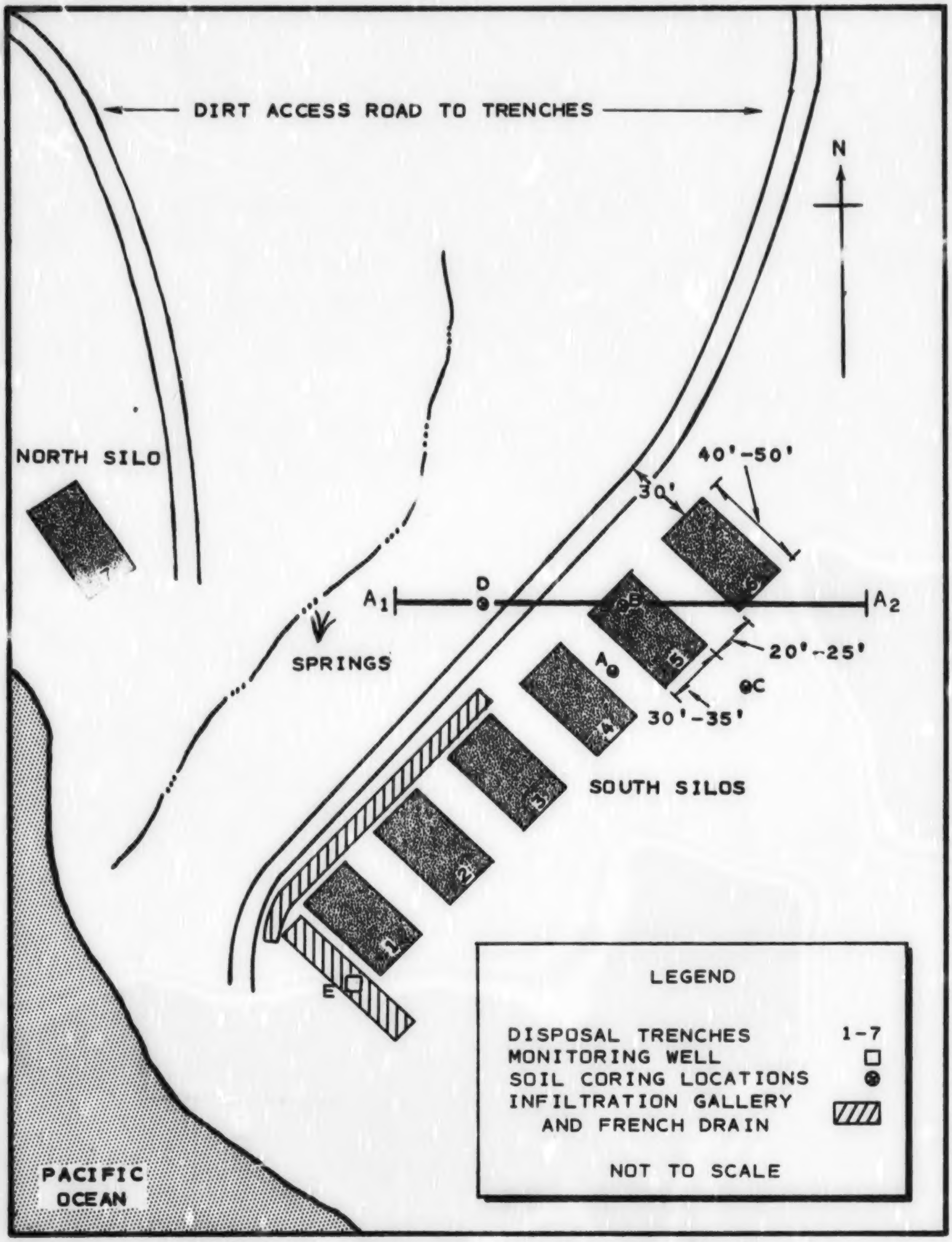
DIRT ACCESS ROAD TO TRENCHES
N
NORTH SILO
7
SPRINGS
D
A1
A2
A
C
E
30'
40'-50'
20'-25'
30'-35'
1
2
3
4
5
6
SOUTH SILOS
PACIFIC OCEAN
LEGEND
DISPOSAL TRENCHES 1-7
MONITORING WELL □
SOIL CORING LOCATIONS ⊗
INFILTRATION GALLERY AND FRENCH DRAIN ▨
NOT TO SCALE

FIGURE 24. SITE MAP - CASE STUDY SITE C.

TABLE 17. SUMMARY OF CLIMATOLOGICAL DATA - CASE STUDY SITE C

Month	Average Monthly Temperature*		Precipitation (annual)*		Evaporation+	
	°F	°C	in	cm	in	cm
Jan.	50	10	4.50	11.4	2.13	5.3
Feb.	53	12	3.60	9.1	2.11	5.3
March	54	12	2.90	7.4	4.31	10.9
April	55	13	1.40	3.6	4.54	11.4
May	57	14	0.63	1.6	7.11	17.9
June	59	15	0.14	0.4	7.63	19.2
July	58	14	0.01	0.0	9.98	25.2
Aug.	59	15	0.04	0.1	10.08	25.4
Sept.	62	17	0.22	0.6	6.17	15.6
Oct.	61	16	0.89	2.3	3.91	9.8
Nov.	57	14	2.00	5.1	2.36	5.9
Dec.	52	11	4.27	10.8	1.36	3.4
Annual	56	13	20.60	52.4	61.69	156.6

*Based upon 1931-1960 data.
+Based upon 1975 data.

moderate to slow permeability (4×10^{-4} to 1.3×10^{-3} cm/sec). Drillings during installation of monitoring wells on March 24, 1976, and subsequent soil analysis confirmed this characterization. A profile of the uppermost 4 m (13.1 ft) of soil is shown on Figure 25, based on sieve analyses performed on soil samples taken from Site C.

Monterey shale underlies the surface soils to an undetermined depth. This Miocene shale formation is very fissile and fractured as noted in nearby outcrops. Figure 26 shows a cross-section at Site C through one of the debris disposal silos.

Groundwater

Characteristics of the subsurface hydrology of the site can be described on the basis of well observations on March 24 and May 15, 1976, and available background data for the area. There is apparently no defined groundwater system in the vicinity of the site. The nearest producing groundwater wells are located approximately 3.1 km (2 mi) northeast of the site. There, three wells draw 0.95 to 1.9 ℓ/sec (2 to 4 cfs) from a blue sand at about 61 m (200 ft). A well approximately 1.61 km (1 mi) to the northeast was drilled to a depth of 762 m (2500 ft) without encountering sufficient water for pumping. A nearby city (4 km east of the site) derives its municipal water supply from local dammed surface waters.

On March 24, 1976, water was observed in the previously installed on-site well (called Well E in this report) and in the recently installed Well B. Figure 23 shows the well locations. Water was observed in Wells B and E again on May 15, and also in Well D. The lack of water in Well C on both occasions could result from several subsurface conditions. Determination of these conditions was beyond the scope of this project. In addition, several springs downgrade from Wells B and D in the interfluve west of Well D were noted during May. These springs were active although no rain had fallen in the area for approximately 6 weeks. The small amount of water observed emanating from the springs discharged into the ocean.

Water observed in Wells B and D is probably the result of water movement through a fracture system within the upper layers of the fissile shale. Water elevation measurements in Wells B, D, and E based on relative elevations of the well casings determined in the field, and the presence of springs to the west and at a lower elevation than the wells suggest that under normal hydrological conditions groundwater moves from east to west (see Figure 31). The origin or areal extent of this groundwater was not determinable within the scope of this project.

Surface Water

No permanent surface water is present at the site. As

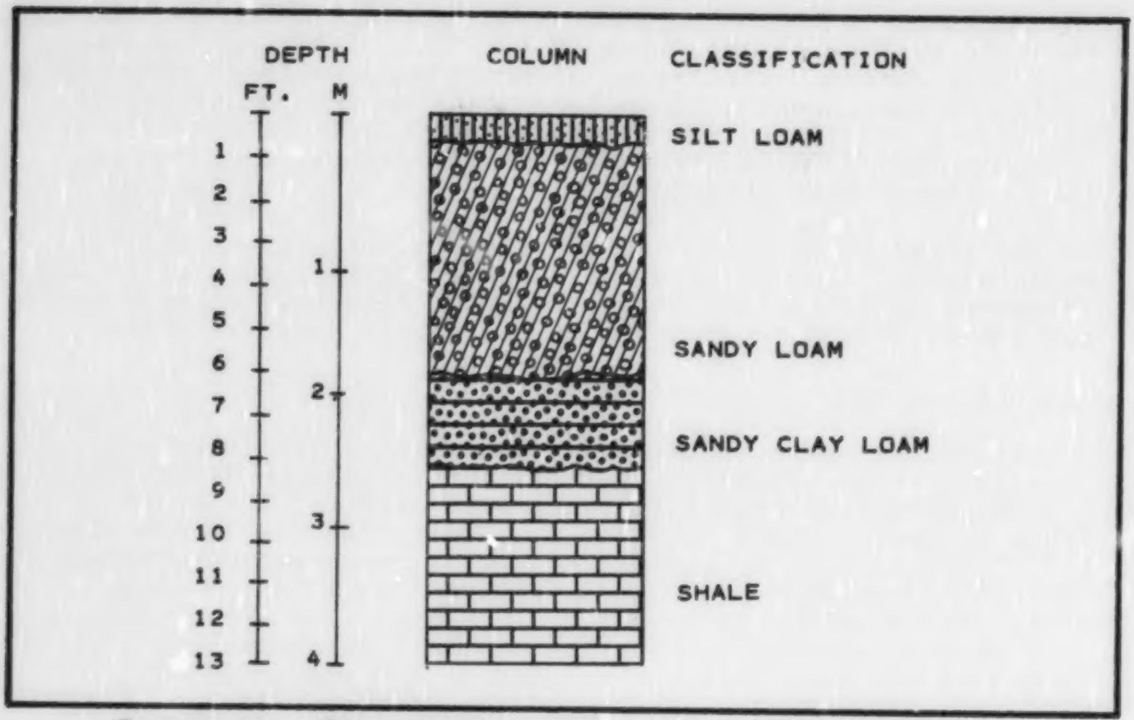
DEPTH
FT.
M
1
2
3
4
5
6
7
8
9
10
11
12
13
1
2
3
4
COLUMN
CLASSIFICATION
SILT LOAM
SANDY LOAM
SANDY CLAY LOAM
SHALE

FIGURE 25. SOIL PROFILE BASED UPON SIEVE ANALYSIS – CASE STUDY SITE C.

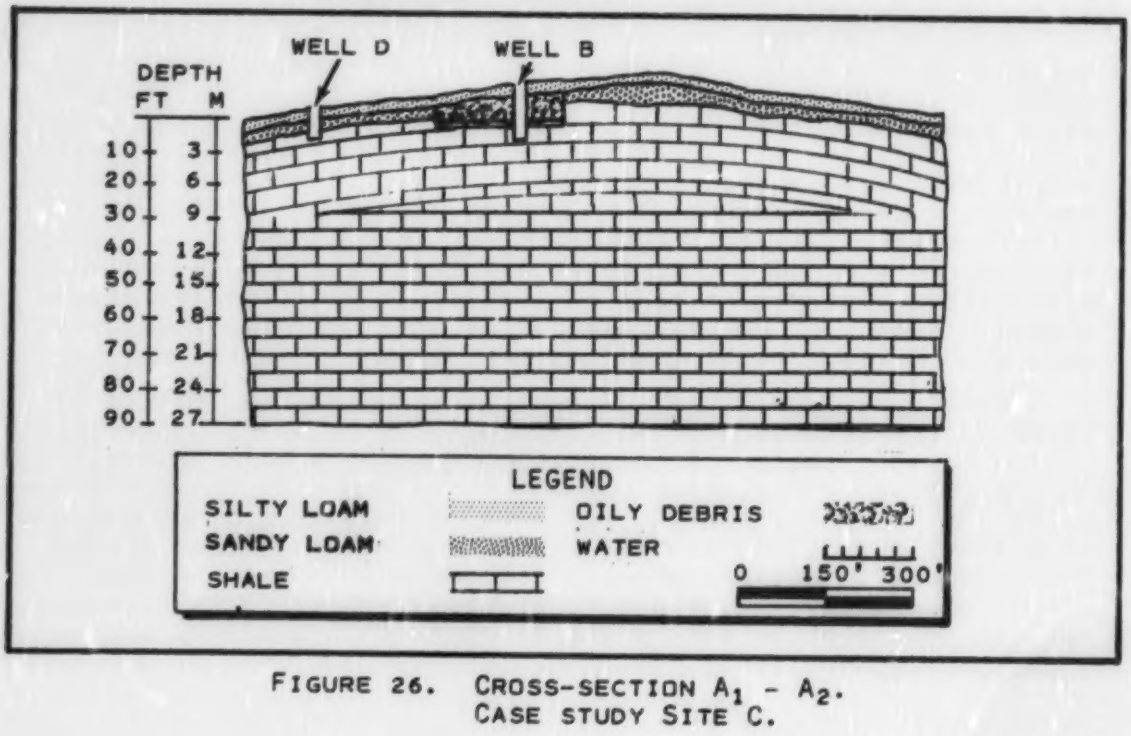
WELL D
WELL B
DEPTH
FT
M
10
20
30
40
50
60
70
80
90
3
6
9
12
15
18
21
24
27
LEGEND
SILTY LOAM
SANDY LOAM
SHALE
OILY DEBRIS
WATER
0
150'
300'

FIGURE 26. CROSS-SECTION A_1 – A_2. CASE STUDY SITE C.

noted, several natural channels drain the site. These channels empty both surface runoff and groundwater discharged from the fractured shale into the ocean on the west.

Oil Spill Debris Disposal

Debris deposited at this site reportedly consisted of the following materials:

- Bunker fuel oil (9.3 API Gravity, viscosity 165 to 175 ssu @ 122°F);
- Oil-coated beach sand;
- Oily straw; and
- Seaweed.

Corings into the debris mass at Well B on March 24, 1976, intersected mostly oil-coated beach sand. Small amounts of straw and seaweed were also observed.

A total of about 3,060 m^3 (4,000 cu yd) of oil spill debris was deposited in the seven trenches at the site.

Debris Disposal Activities

An accident at sea caused 3 to 5 m^3 (about one thousand gal) of bunker fuel oil to spill into the Pacific Ocean. Much of this oil, along with some seaweed, washed up on beaches north of San Francisco. Cleanup efforts entailed removal of oil-coated beach sand and stockpiling at a beach parking lot while options for debris disposal were investigated.

The nearest sanitary landfills were situated about 30 to 35 km (19 to 22 mi) from the stockpile sites. Access to these established sites was via secondary highways that were not well-suited for the heavy truck traffic that would be necessary to remove accumulated debris. Accordingly, a more local disposal area was sought.

Review of available geologic and soils information and land ownership records resulted in selection of Site C. Permission to use the site for debris disposal was secured, and disposal activities commenced about one week after cleanup operations began.

At the disposal site, seven silos were excavated into the hillsides, using scrapers and track dozers. Figure 27 shows an aerial view of the site during silo construction and disposal operations. Ripper attachments were used to remove the shale material from below depths greater than 1.5 to 2.3 m

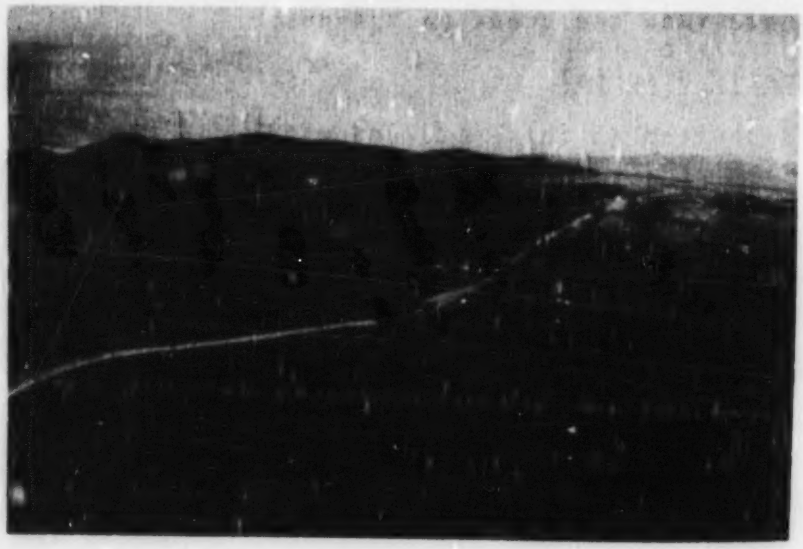

FIGURE 27. AERIAL VIEW OF DISPOSAL OPERATIONS AT CASE STUDY SITE C, 1971.

FIGURE 28. PARTIALLY COMPLETED SILO BEING FILLED - SITE C.

(5 to 7.5 ft). Silos were excavated to about 3.7 to 5.5 m (12 to 18 ft) deep. The silos vary somewhat in size; the range of typical dimensions and spacings between silos is indicated on Figure 24. A photo taken during construction is shown in Figure 28. Figures 29 and 30 illustrate typical trench cross-sections before and after filling with debris.

After completion of the first silo and during excavation of the others, debris began to be hauled from the stockpile near the cleanup site to the disposal silos. Double-axle dump trucks and tractor-trailer rigs were used for debris transportation. Oil spill debris was deposited directly into the silo mouth from the dirt access road.

The silos were filled with alternate layers of debris and previously-excavated soil, as depicted in Figure 29. The intermediate soil cover was used to provide a firmer footing for debris delivery trucks when discharging their loads into the silos. A final soil cap, 0.9 to 1.2 m (3 to 4 ft) thick was placed on the top of each completed silo to impede infiltration of precipitation. Approximately two-thirds of the volume of each silo is filled with debris. The remaining volume is occupied by intermediate and final soil cover.

All oil spill debris was buried within approximately one month. The land surface was graded to conform as closely as possible to surrounding undisturbed contours. Grass seed was applied, but insufficient moisture prevented germination. A runoff diversion channel was cut into the natural ground upgrade from each of the silos. Another channel was cut next to the road at the toe of each silo.

Routine Monitoring and Corrective Actions

Periodic examination of the site, after completion of disposal operations, indicated some ponded water in the drainage trench at the toe of several silos. An oily sheen was noted on this water. Also, some oil was observed in patches, oozing through the cover soil.

Thus, as a precaution, a gravel-filled trench was installed in late 1971 on the southwest end of the south silos and at the base of Silos 1, 2, and 3 to intercept any groundwater that may have contacted the oil spill debris. A steel-cased well (Well E) was placed southwest of the six south silos in the French drain (see Figure 24). As of May 1976, no visible migration of oil has been observed, following these corrective actions.

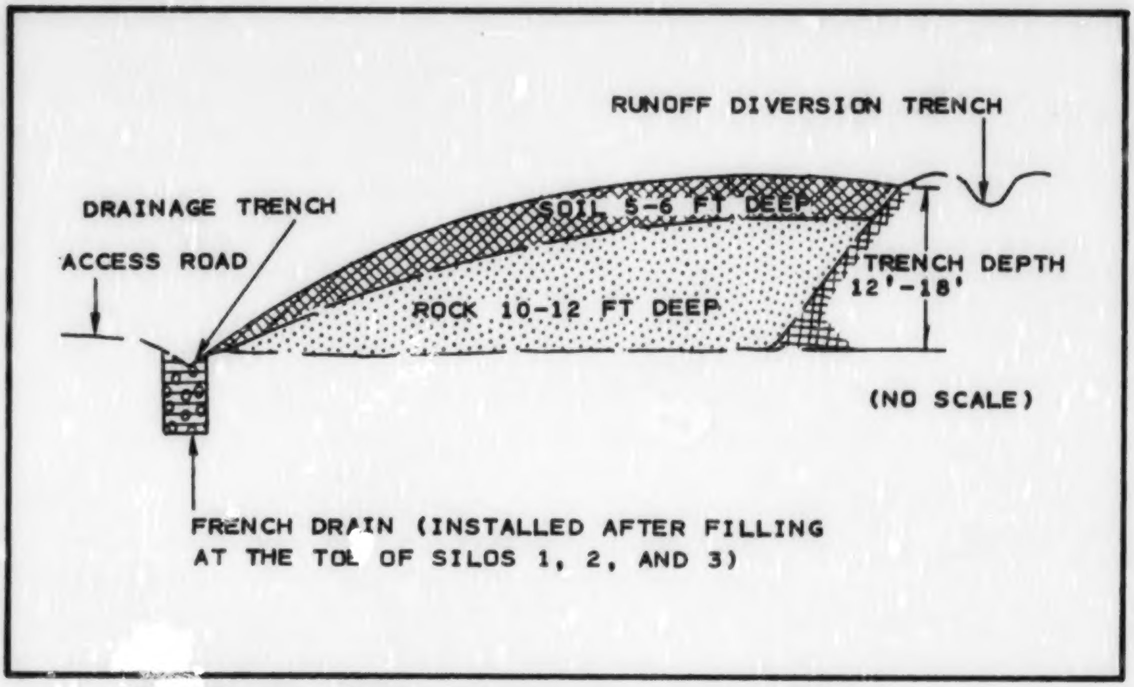
RUNOFF DIVERSION TRENCH
DRAINAGE TRENCH
SOIL 5-6 FT DEEP
ACCESS ROAD
TRENCH DEPTH
12'-18'
ROCK 10-12 FT DEEP
(NO SCALE)
FRENCH DRAIN (INSTALLED AFTER FILLING
AT THE TOE OF SILOS 1, 2, AND 3)

FIGURE 29. CROSS-SECTION OF TYPICAL DEBRIS DISPOSAL SILO BEFORE FILLING - SITE C.

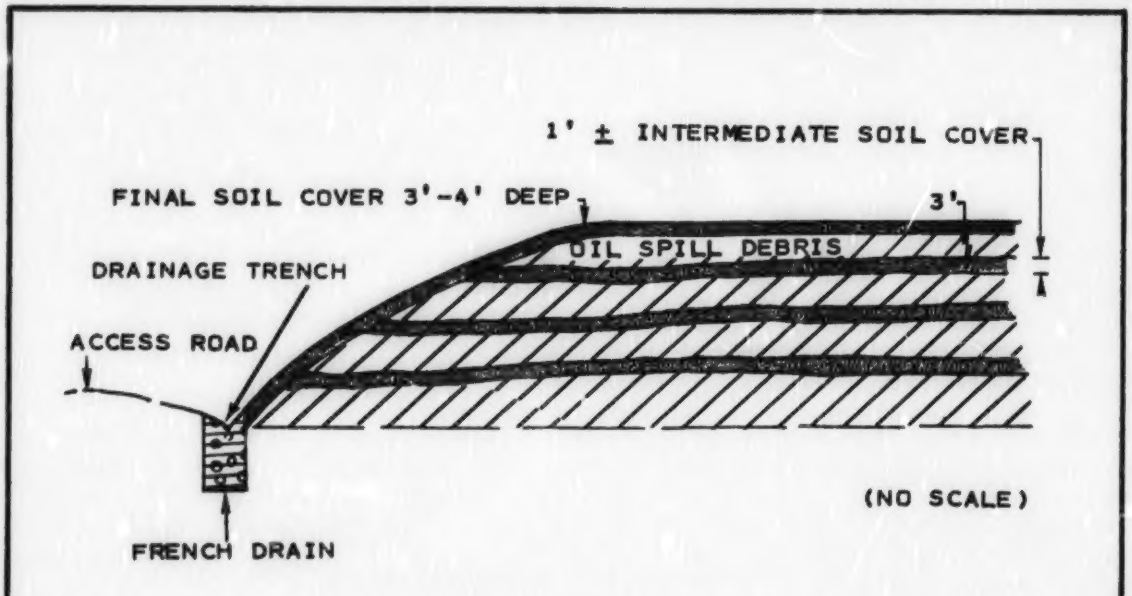
1' ± INTERMEDIATE SOIL COVER
FINAL SOIL COVER 3'-4' DEEP
3'
OIL SPILL DEBRIS
DRAINAGE TRENCH
ACCESS ROAD
(NO SCALE)
FRENCH DRAIN

FIGURE 30. CROSS-SECTION OF TYPICAL DEBRIS DISPOSAL SILO AFTER FILLING - SITE C.

Case Study Monitoring

A limited monitoring program was devised for case study Site C to determine the following basic information:

- Environmental effects of burying oil spill debris; and
- Apparent degradation rates of oil spill debris under low-oxygen, high-humidity conditions.

A total of nine corings were drilled at the site on March 24. Four of these corings were cased and are designated as Wells A, B, C, and D. Their locations and depths are shown on Figure 31. Well E was already placed at the time of case study monitoring.

The well locations were selected to provide information on any oil migration patterns and to obtain samples of oil spill debris from a sequestered burial area. The rationale for placement of each well is as follows:

- Well A - Situated between two silos, soil and water samples from this well would indicate if any lateral migration of oil through the soil has occurred.
- Well B - Oil spill debris samples from various levels within the disposal silo would show the extent to which oil migrates downward within the debris mass, if it migrates at all.
- Well C - Background soil and water characteristics would be obtained from this well, located upstream from the area of debris disposal.
- Well D - Samples from this apparent downstream well would indicate the extent to which oil migrates downgradient away from debris disposal area.

All wells were drilled with a 20 cm (8 in) auger and cased with 12 cm (5 in) PVC pipe. The bottom 0.9 m (3 ft) of each pipe was grooved to facilitate water infiltration into the well.

Soil samples and oil spill debris were obtained at several intervals during the well drilling, as shown on Figure 31. Soil samples obtained during the drilling exhibited isotropic conditions between wells, indicating a consistent subsurface regimen within the study area.

Water samples were taken from Wells B and E on the day of drilling (March 24); no water was detected in Wells A, C, or D. On subsequent well-sampling on May 15, water was found in Wells B, D, and E. The water level in Well B (in the silo) was

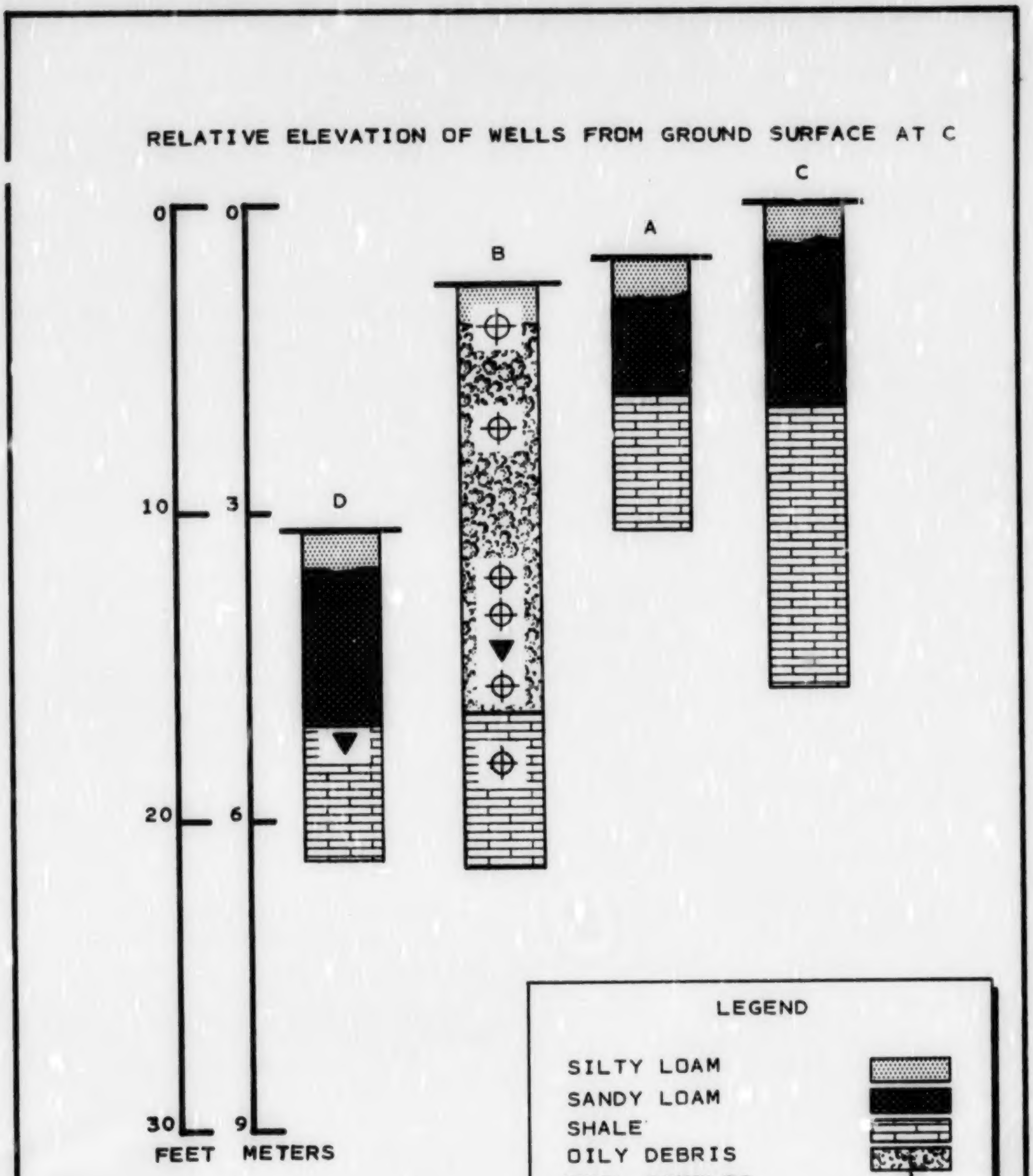
RELATIVE ELEVATION OF WELLS FROM GROUND SURFACE AT C
0
10
20
30
FEET
0
3
6
9
METERS
D
B
A
C
LEGEND
SILTY LOAM
SANDY LOAM
SHALE
OILY DEBRIS
SOIL SAMPLES
WATER LEVEL (5-15-76)
NOT TO SCALE

FIGURE 31. WELL LOGS- CASE STUDY SITE C.

approximately 0.75 m (2.5 ft) higher than the depth measured in March. Well C was still dry.

Analytical Results

Tables 18 and 19 show results of the various analyses performed on soil, oil spill debris, and groundwater samples obtained from case study Site C. Plots of the hexane extractable (paraffin) fraction of each sample analyzed for oil content were also obtained and reviewed. Reported oil concentrations include both dissolved and free oil.

Data Evaluation

Evaluation of the analytical results on Tables 18 and 19, in relation to the sample locations and probable groundwater flow is discussed below.

There is apparently no downward migration of oil from the upper layers of the oil spill debris to the lower layers, since no pattern of increased oil content with depth is observed for in silo samples.

Water sampled from Well B (in Silo 5) in March contained 107.5 mg/l oil. No water was observed in any other of the newly installed wells (A, C, and D) at that time. In May, water samples were obtained from Wells B and D. Well D is located approximately 9 m (30 ft) from Well B. Water levels had increased by about 0.7 m (2.2 ft) in both Wells B and D since March, even though no precipitation had fallen during the interim.

As shown on Table 18, the May water sample from Well B contained 499 mg/ℓ of oil and the Well D water sample contained 18 mg/ℓ oil. Table 19 shows that water from Well D had an oil content of 16.2 mg/ℓ. The paraffin, aromatic, and polar fractions of the oil from each well were similar, suggesting that oil in Well D water could be from the silos. However, oil from soil at the surface of Wells B and C was somewhat similar to the oil found in water samples from Wells B and D, indicating that the oil detected in Well D water is from background sources, not from the buried debris.

Overall, the monitoring results provide no conclusive evidence that groundwater flowing through the spill debris has leached oil or carried any oil downstream. It is not possible to determine if any of the oil detected in Well D was the result of lateral oil migration because:

(1) Well water contamination may have resulted from drilling or sampling, or from tampering by unauthorized visitors to the site.

TABLE 18. RESULTS OF SOIL AND WATER SAMPLE ANALYSES

WELL B -
CASE STUDY SITE C

Well/ Sample No.	Type of Sample	Depth of Sample		Moisture Content	Organic Acid	Total Organic Nitrogen	PO_4	Pb	Fe	Aerobic	Anaerobic	Yeast & Mold
		m	ft	% by wt.	ppm					Plate Count (1000's)		
1	Soil	Surface		-	-	-	-	-	-	-	-	-
2	Oily sand	1.0	3	10.7	1410	357	1497	11	16,125	42	1	0.93
3	Oily sand	1.5	5	10.3	60	289	143	13	10,390	102	0	1.15
4	Oily sand	2.2	7	22.7	420	546	823	2	9,975	90	1	0.70
5	Oily sand	3.0	10	19.9	60	459	729	12	16,875	60	0.2	1.25
6	Oily sand	3.7	12	16.1	60	224	767	6	7,080	210	0.05	0.06
7	Oily sand	4.6	15	19.8	252	785	1507	16	20,560	3	4	0.02
7*	Oily straw, sand	4.6	15	-	-	-	-	-	-	-	-	-
8	Water	4.3	14	NA	20	10	0.46	0.40	193	26	0.3	0.90
8*	Water	3.7	12	NA	25	25	0.36	0.06	1	880	0.8	1.4

*All samples collected March 24, 1976, except those marked * (taken May 15, 1976).

TABLE 18 (continued)

Well/ Sample No.	Type of Sample	Depth of Sample		Parameter				
				Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
		m	ft			Paraffin	Aromatic	Polar
1	Soil	Surface		3.62	3.27	17.4	13.6	68.9
2	Oily sand	1.0	3	2.07	1.96	11.7	9.8	78.4
3	Oily sand	1.5	5	0.04	0.02	10.4	4.4	85.0
4	Oily sand	2.2	7	0.47	0.30	16.0	8.8	75.0
5	Oily sand	3.0	10	0.31	0.12	19.6	9.0	71.2
6	Oily sand	3.7	12	5.56	5.08	15.4	16.2	68.2
7	Oily sand	4.6	15	0.57	0.45	11.9	4.1	83.9
7*	Oily straw, sand	4.6	15	10.80	10.16	17.4	19.6	63.0
8	Water	4.3	14	124.7 mg/l	107.5 mg/l	21.3	18.1	60.4
8*	Water	3.7	12	513.9 mg/l	498.7 mg/l	16.5	24.6	58.8

*All samples collected March 24, 1976, except those marked * (taken May 15, 1976).

TABLE 19. RESULTS OF SOIL AND WATER SAMPLE ANALYSES

WELLS C, D, AND E -
CASE STUDY SITE C

Well/ Sample No.	Type of Sample	Depth of Sample		Moisture Content	Organic Acid	Total Organic Nitrogen	PO4	Pb	Fe	Aerobic	Anaerobic	Yeast & Mold
		m	ft	% by wt	ppm					Plate Count (1000's)		
C 1	Soil	3	10	31.9	-	-	-	-	-	-	-	-
D 1	Soil	Surface		16.9	<5	2163	1113	11.0	15,625	1134	65	128
2*	Water	1.5	5	NA	<5	7.5	<0.3	0.05	0.29	500	16	<1
E 1	Water	3.6	12	NA	227	0.56	0.03	0.25	16.2	<1	0	<<1

*All samples collected March 24, 1976, except those marked * (taken May 15, 1976).

TABLE 19 (continued)

Well/ Sample No.	Type of Sample	Depth of Sample		Parameter				
				Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
		m	ft			Paraffin	Aromatic	Polar
C 1	Soil	3.0	10	0.39	0.31	15.6	7.5	76.8
D 1	Soil	Surface		0.27	0.12	26.5	29.9	43.5
2*	Water	1.5	5	18.0 mg/l	16.2 mg/l	18.3	18.9	62.6
E 1	Water	3.6	12	21.8 mg/l	20.6 mg/l	1.8	0.2	97.8

*All samples collected March 24, 1976, except those marked * (taken May 15, 1976).

(2) No background water sample was available to provide base data from which to evaluate the sampling and analytical procedures. (Well C was dry during both March and May, and no nearby water supply wells were available.)

(3) No duplicate measurements were made. The scope of this project permitted only a limited number of soil and water samples to be obtained and analyzed.

Phosphate and organic nitrogen concentrations in the surface sample at Well D are relatively high. This is likely due to runoff of fertilizer formerly applied on the silos to encourage revegetation. Also, the cattle manure could be a source of nitrogen.

Conclusions and Recommendations for Further Studies--

There are no conclusive results to indicate that groundwater flowing through the oil spill debris disposal silos has leached oil and carried it downstream. It is possible that groundwater flowing through the oil spill debris silos has leached oil and carried it downstream, but the evidence is not conclusive. Periodic sampling of water in the existing wells could provide additional information, especially during and after the winter rainy season. Also, installation of other wells upstream from the silos and drilled to groundwater will enable determination of background water quality data for comparison.

REFERENCES

1. Climates of the States. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, 1973. p. 572.

2. Climatological Data. California Annual Summary, 78(13), National Oceanic and Atmospheric Administration, Environmental Data Service, 1974.

3. General Soils Map of Marin County. U.S. Dept. of Agriculture, Soil Conservation Service. p. 73.

4. Geologic Map of California, San Francisco Sheet. State of California Dept. of Natural REsources, 1967.

SECTION 4 - CASE STUDY SITE D, CRANSTON, RHODE ISLAND

Background

Grounding of the M/T Pennant in Narragansett Bay in 1973 resulted in spillage of approximately 3,500 m^3 (100,000 gal) of #6 fuel oil. The oil washed up on recreational beaches in the area and was collected and stockpiled along with oil-contaminated solid debris and sand.

Location of a debris disposal site was delayed for almost one year due to public opposition to receipt of the material and the unwillingness of sanitary landfill operators outside the immediate area to accept the debris. Ultimately, an agreement was reached between the Rhode Island Department of Transportation, the U.S. Coast Guard, and EPA to bury the oil spill debris at a state-owned spent sand quarry, used for department business, known as the Howard complex near Cranston, Rhode Island.

This site was selected for case study as representative of oil spill debris disposal by burial in a cool, humid climate where site preparation was required.

The city of Cranston is located approximately 8.2 km (5 mi) south of Providence, and 4.1 km (2.5 mi) west of Narragansett Bay. As noted on Figure 32, the site is about 0.9 km (0.5 mi) east of Cranston proper and lies in the southern portion of a 20.2 ha (50 ac) excavated sand pit. The oil spill debris disposal area encompasses a rectangular portion of the pit of approximately 0.4 ha (1 ac). Access from the highway is via a dirt road from the north part of the site. Figure 33 is a photograph taken from about Well 7 looking north northeast on April 21, 1976.

The topography of the Cranston site is typical of a coastal plain environment. Relief is gentle with nearby terraces forming the only immediate relief. The oil spill debris disposal area lies within an abandoned sand quarry that has been excavated to an essentially level floor. The floor is approximately 6 m (20 ft) below the surrounding relief, as indicated on Figure 34.

The Rhode Island Department of Transportation acquired the spent sand quarry for use as an equipment and material storage area. The site is located in the midst of an urban area. Interstate 95 is within 1 km (0.6 mi) to the east and Pawtuxet River is 152 m (500 ft) away, also to the east. Adjacent land is used for a state prison to the south, a major hospital to the west, and light industrial facilities to the north.

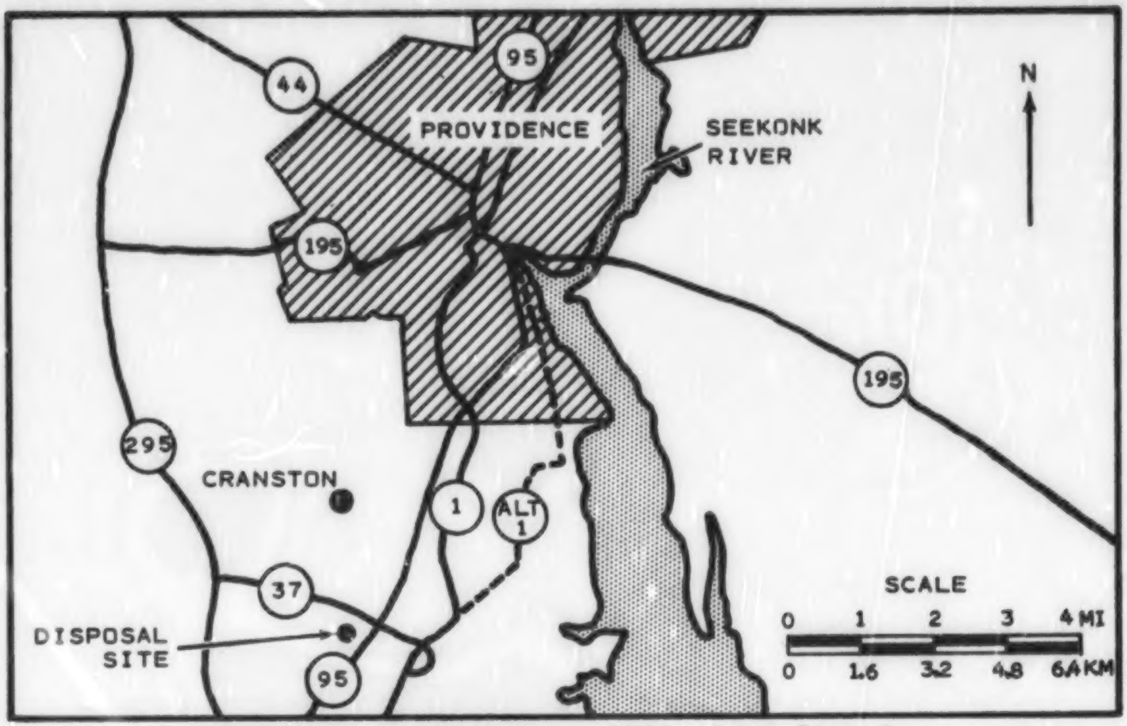
95
44
PROVIDENCE
SEEKONK
RIVER
N
195
195
295
CRANSTON
1
ALT 1
37
DISPOSAL
SITE
95
SCALE
0 1 2 3 4 MI
0 1.6 3.2 4.8 6.4 KM

FIGURE 32. LOCATION OF CASE STUDY SITE D - CRANSTON, RHODE ISLAND.

FIGURE 33. VIEW OF DISPOSAL SITE SURFACE - SITE D (APRIL 26, 1976).

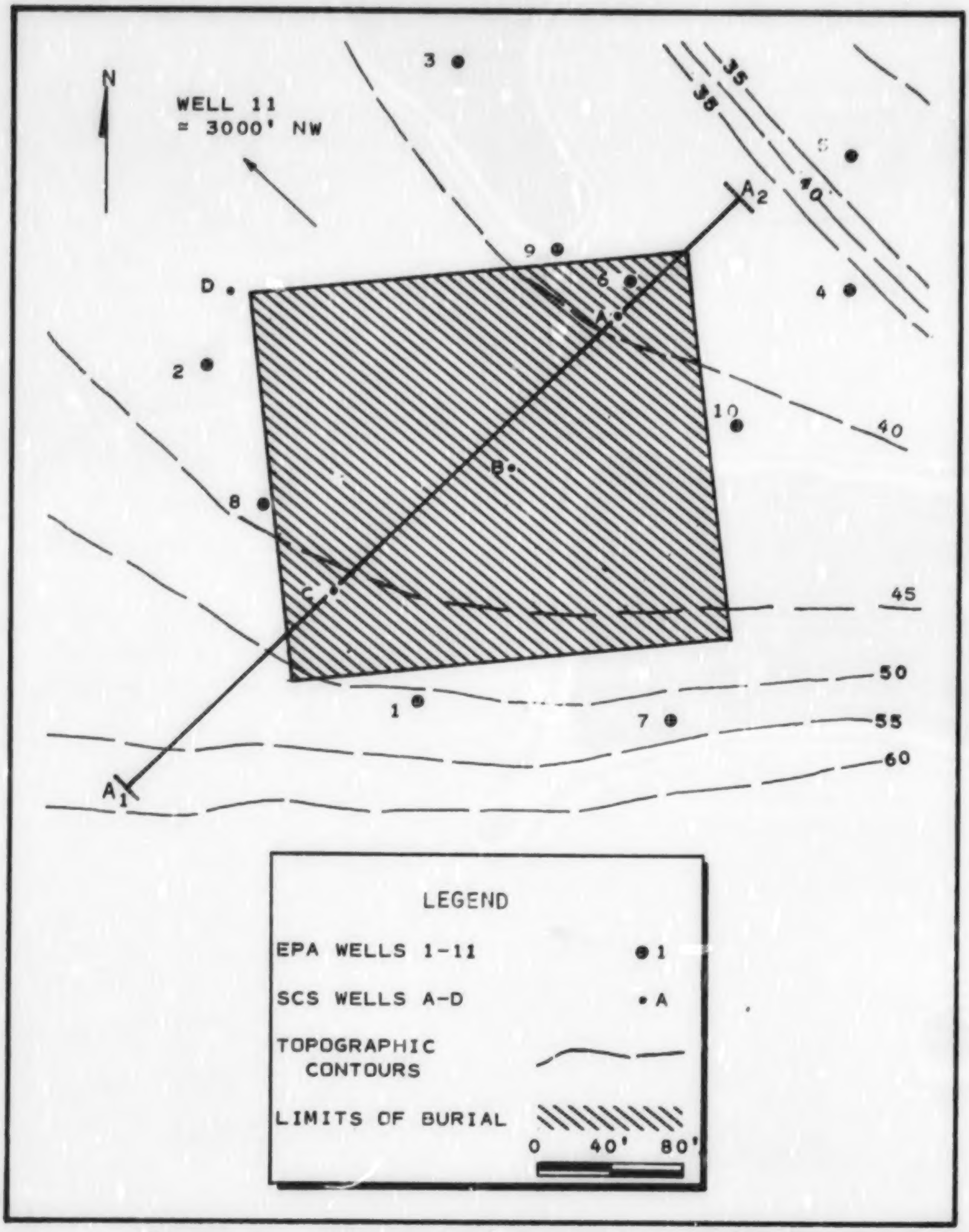
N
WELL 11
≈ 3000' NW
3
35
38
5
40
A2
9
6
D
A
4
2
10
40
B
8
C
45
50
1
7
55
60
A1
LEGEND
EPA WELLS 1-11
● 1
SCS WELLS A-D
• A
TOPOGRAPHIC CONTOURS
LIMITS OF BURIAL
0
40'
80'

FIGURE 34. SITE MAP AND GROUNDWATER MOVEMENT. CASE STUDY SITE D.

Climate

Climatological data for the area are summarized on Table 20. Temperatures in the area vary from lows of -2°C (28°F) to highs of 20°C (71°F). Annual precipitation is 100.7 cm (39.63 in) (1).

Geology and Soils

Geological and soil conditions at the Cranston site are typical of the Piedmont Plateau Province of fine coastal sediments (2). Figure 35 shows the estimated subsurface conditions on a cross-section of this site. Hydraulic conductivity tests of soil samples from the site show rapid permeability. A soil profile developed from representative sieving tests is shown on Figure 36. Homogeneity of this typical profile probably extends to a depth of at least 4.5 m (15 ft), based upon coring data obtained during this sampling program and previous EPA borings.

Below the unconsolidated soils lies a layer of compacted till. This till presumably rests upon a bedrock of dark shale.

Groundwater

Characterization of the subsurface hydrology at Site D is based on sampling information from April 21, 1976, and on available literature data for the area. Groundwater elevations in on-site wells indicate that shallow groundwater exists in the area of the site at depths ranging from 3.0 to 6.0 m (10 to 20 ft). The shale bedrock is assumed to form the lower boundary of this aquifer. Seasonal variations based upon static water levels in 11 EPA monitoring wells indicate a seasonal fluctuation in both depth and direction of flow. Seasonal differences apparently account for a 1.2 m (4 ft) static water level fluctuation.

Direction of flow is also seasonal alternating between south and southeast. Groundwater discharge is assumed to occur at Pawtuxet Creek to the southeast of the site.

Surface Water

No permanent surface water is present at the site. Level relief and highly permeable soils account for the lack of any runoff from the site or for the absence of any standing waters.

Debris Disposal Activities

On April 9, 1973, the M/T Pennant ran aground in Narragansett Bay. The incident resulted in an oil spill that contaminated recreational beaches in the immediate area with oil and oil-soaked debris. It was estimated that approximately 3,500 m^3 (100,000 gal) of #6 fuel oil were spilled in the incident.

TABLE 20. SUMMARY OF CLIMATOLOGICAL DATA - CASE STUDY SITE D

Month	Average Monthly Temperature*		Precipitation (annual)*		Evaporation$^+$	
	°F	°C	in	cm	in	cm
Jan.	28.7	-2	3.75	9.5	--	--
Feb.	28.6	-2	2.84	7.2	--	--
March	36.8	+2	3.58	9.1	--	--
April	46.0	8	3.37	8.6	--	--
May	56.8	13	3.02	7.7	4.89	12.4
June	65.6	18	3.17	8.1	4.89	12.4
July	71.0	22	3.06	7.8	5.54	14.1
Aug.	69.4	21	3.63	9.2	4.67	11.9
Sept.	62.7	17	3.19	8.1	3.26	8.3
Oct.	52.7	11	2.83	7.2	3.30	8.4
Nov.	42.6	6	3.74	9.5	--	--
Dec.	31.6	0	3.45	8.8	--	--
Annual	49.4	9.5	39.63	100.8	26.55	67.5

* Based upon 1931-1960 data.

$^+$ Based upon 1975 data.

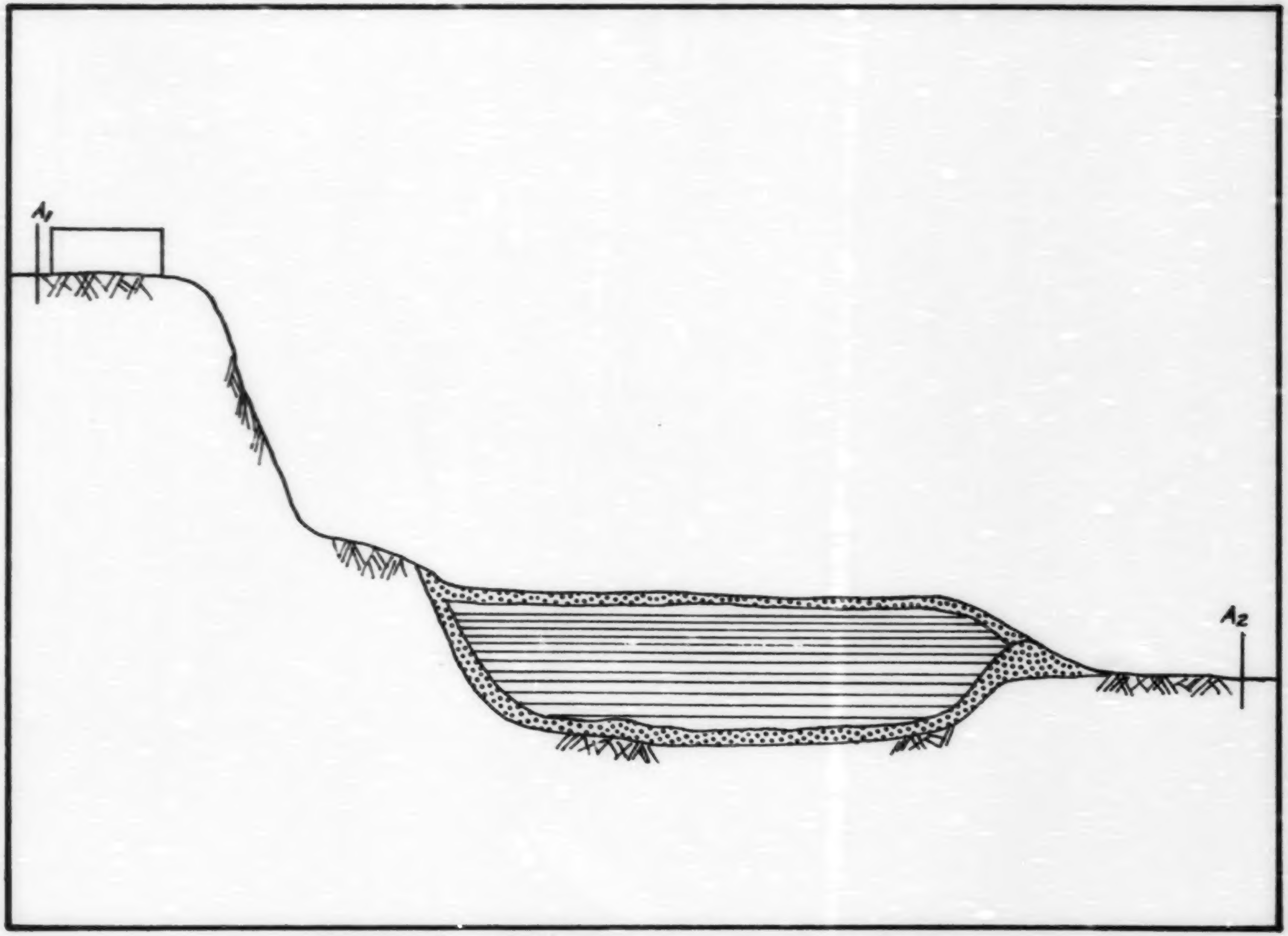

FIGURE 35. CROSS-SECTION, CASE STUDY SITE D.

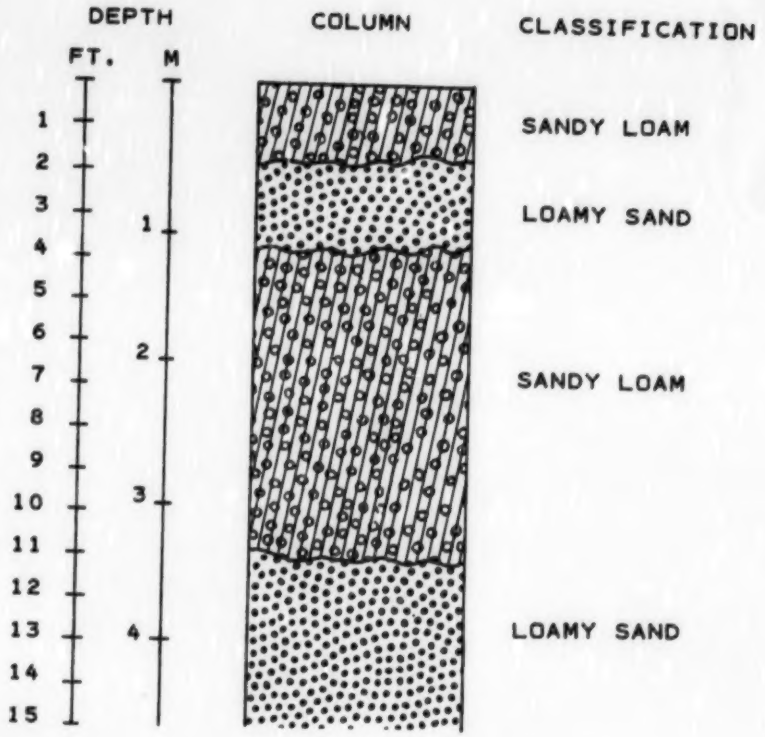
DEPTH
FT.
M
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1
2
3
4
COLUMN
CLASSIFICATION
SANDY LOAM
LOAMY SAND
SANDY LOAM
LOAMY SAND

FIGURE 36. SOIL PROFILE BASED UPON SIEVE ANALYSIS - CASE STUDY SITE D.

An estimated 6,500 m^3 (8,500 cu yd) of oil spill debris were collected during cleanup and deposited at Site D. The debris reportedly consisted of the following materials:

- #6 fuel oil;
- Oil-soaked sand and gravel;
- Seaweed and straw.

Various other items including tires, large timbers, bricks, oil-soaked barrels, and soiled clothing were also collected. Corings into the debris mass on April 21, 1976, encountered examples of these materials within various cell layers.

Collected debris was initially stockpiled on a nearby beach parking lot while a search for a permanent disposal site was initiated by officials from EPA's Region I office and the Rhode Island Department of Health. As the summer approached and demand for the parking lot increased, the debris was moved in May, 1973, to another temporary stockpile area at the Howard complex of Rhode Island's Department of Transportation.

Throughout the summer of 1973, EPA and state officials continued searching for an ultimate disposal site for the stockpiled debris. Also, alternative disposal methods were investigated in more detail by EPA personnel. Methods included incineration and land disposal. Since no special incinerator was available, engineers concentrated on designing a land disposal scheme that afforded maximum environmental protection.

In March, 1974, Rhode Island officials granted permission to bury the oil spill debris at the stockpile site in Cranston, according to a special disposal plan devised by EPA's Region I (3).

The disposal plan, depicted in Figure 37, called for placement of a layer of locally available silty soils to impede or prevent outward migration of any water, oil, or oil-water emulsion. Debris would be deposited in layers with intermediate cover soil added as shown. A cap of fine-grained soil was specified for the final cover. In addition, the plans included a thorough system of groundwater monitoring wells and a five-year monitoring program to be performed by EPA.

Disposal operations began in the spring of 1974 and continued through June. Prior to initiating disposal activities, five monitoring wells were established to determine groundwater characteristics and background water quality data. These wells were later determined to be too shallow to intersect groundwater at all times during the year. The disposal site was first excavated to a depth of approximately 0.9 m (3 ft) and graded at

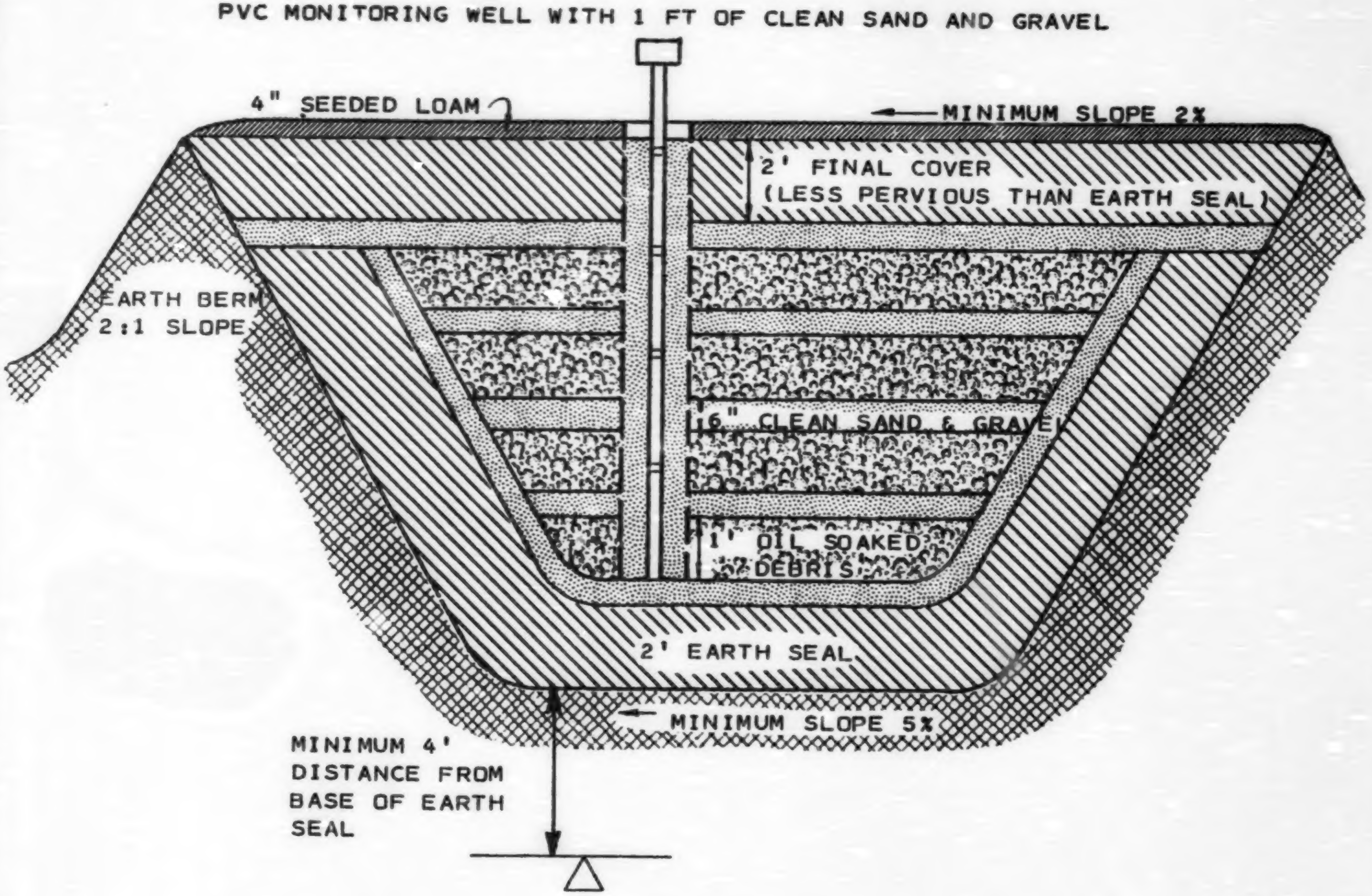
PVC MONITORING WELL WITH 1 FT OF CLEAN SAND AND GRAVEL
4" SEEDED LOAM
MINIMUM SLOPE 2%
2' FINAL COVER
(LESS PERVIOUS THAN EARTH SEAL)
EARTH BERM
2:1 SLOPE
6" CLEAN SAND & GRAVEL
1' OIL SOAKED
DEBRIS
2' EARTH SEAL
MINIMUM SLOPE 5%
MINIMUM 4'
DISTANCE FROM
BASE OF EARTH
SEAL

FIGURE 37. SECTION VIEW OF EPA DEBRIS DISPOSAL PLAN - CASE STUDY SITE D.

5 percent to a common point. Earth berms were built up to form an encapsulating bowl. The excavation floor and berm walls were lined with 0.6 m (2 ft) of sandy silt, gravel washings obtained from a local sand and gravel extraction operation.

Oil spill debris was then placed into the prepared disposal area according to the plan. The intermediate layers of clean fill were included to improve equipment traction and to provide an absorbtive media to retard and possibly hold any free oil that might flow from the debris. Before completing operations, a monitoring well was placed at the low point as a vent and for later use in determining the presence of water and/or oil in the sump. A final 0.6 m (2 ft) layer of sandy silt was added as a cover cap.

After covering with silty sand, the surface was sown with grass seed. The grass was planted too late, and relatively little growth occurred the first year. The following year, a healthy stand of grasses was established (see Figure 34).

As noted previously, the original five wells placed by EPA were not deep enough to permit groundwater sampling. Consequently, five new wells (numbered 7 through 11) were installed to 0.0 ft mean sea level. The locations of these wells are noted on Figure 34.

Personnel from EPA's Region I offices have monitored the Site D periodically since completion of filling in 1974. Groundwater elevation measurements are taken at Wells 7 through 11. Also, samples of groundwater have been analyzed for total organic carbon (TOC) and phenols several times per year. Analyses to date indicate no groundwater contamination from the landfilling operation has reached the berm walls.

Case Study Monitoring

A limited program to complement existing EPA monitoring at the Cranston site was implemented during this study. The basic purposes of the case study monitoring were to determine the extent to which oily material has migrated from the disposal site and to observe the condition of oil spill debris after confinement to an anaerobic environment for several years in a humid climate.

Four wells were drilled at Site D on April 21 as part of this program. All four wells were cased and designated as A through D. Their location and depths are shown on Figure 38. Wells A, B, and C were placed in the disposal area to obtain samples of oil spill debris and soil liner material. Also, these wells were checked for the presence of water. Well D was drilled to obtain background soil samples. Figure 38 shows the boring logs for these wells.

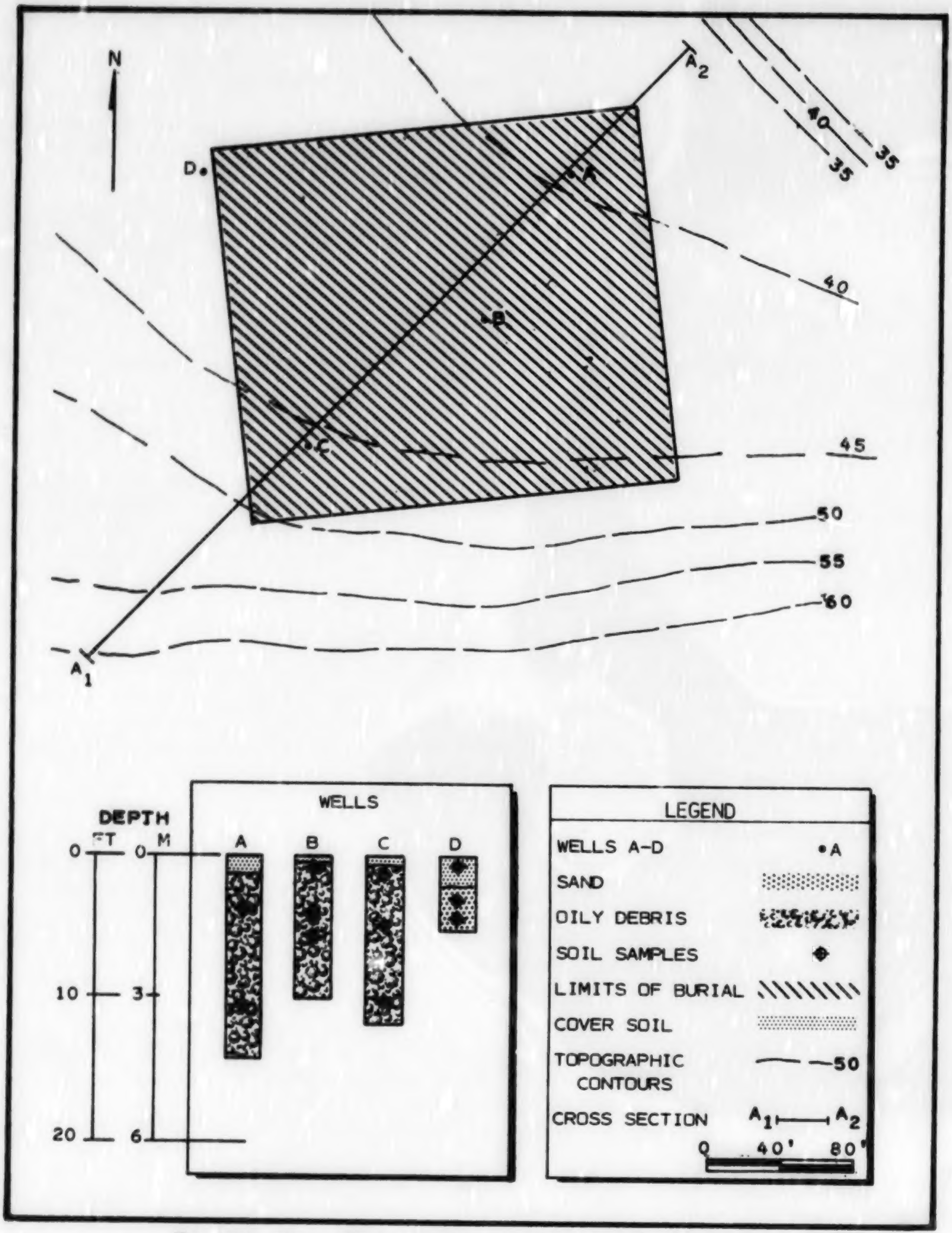
N
A2
D
A
B
C
40
35
35
40
45
50
55
60
A1
DEPTH
FT
M
0
0
10
3
20
6
WELLS
A
B
C
D
LEGEND
WELLS A-D
•A
SAND
OILY DEBRIS
SOIL SAMPLES
LIMITS OF BURIAL
COVER SOIL
TOPOGRAPHIC CONTOURS
50
CROSS SECTION
A1
A2
0
40'
80'

FIGURE 38. WELL LOGS - CASE STUDY SITE D.

Samples of soil and oil spill debris were obtained from various depths in Wells A through D, as shown on Figure 38.

At the time of installation of Wells A through D, water samples were collected from four EPA wells; 4, 9, 10, and 11. EPA Well 6 and Well A, both located in the debris disposal area, had approximately 2 to 4 cm (0.8 to 1.6 in) of water, which was not deep enough to sample. All other wells were dry.

Analytical Results

Tables 21 and 22 summarize the results of the various analyses performed on soil, oil spill debris, and groundwater samples obtained from the Cranston case study site.

Data Evaluation--

Review of the sample analyses in relation to the sample locations and groundwater flow suggests that some oil migration may be occurring from the site. Soil samples from Well D are appreciably lower in oil content than all oily samples obtained from within the disposal area at Well B. However, sample D-3 shows an oil content of the same order of magnitude as all samples from Well C. No conclusions can be drawn from these data, but oil may have migrated to the area of Well D from the burial site several meters away.

There appears to be no downward migration of oil from the upper to the lower cells. The layering of soil between cells has apparently helped contain the oil.

It is interesting to note the predominance of aerobic bacteria in soil and debris samples, including those obtained from 3.0 to 3.4 m (10 to 11 ft) deep in the debris. This suggests that oxygen is reaching the depths of the buried debris. Infiltration of surface waters and/or diffusion through the side berms may be the source of this oxygen. (On the other hand, it may be that aerobic bacteria had sufficient time to establish themselves at the expense of any anaerobes during the two to three day delay between sample procurement and delivery to the laboratory for analysis.)

The concentrations of lead, iron, and chlorides are relatively consistant between soil and debris samples, as noted on Table 19. High phosphate concentrations in Well C in relation to all other samples are not readily explainable.

Examination of Table 20 suggests that some groundwater oil contamination may have occurred. Assuming that samples from Well 11, some 915 m (3,000 ft) upstream from the site, accurately represent background water quality, all water samples from wells near the site show increased oil content concentrations over

TABLE 21. RESULTS OF SOIL AND DEBRIS ANALYSES

WELLS A, B, C, AND D -
CASE STUDY SITE D

Well/ Sample No.	Type of Sample	Depth of Sample		Moisture Content	Organic Acid	Total Organic Nitrogen	PO_4	Pb	Fe	Cl	Aerobic	Anaerobic	Yeast & Mold
		m	ft	% by wt.	ppm						plate count (1000's)		
A 1	Debris	1.3	4.5	10.6	35	918	60	15.8	12.1	17	56,700	27	<1
2	Debris	3.4	11	8.5	25	364	719	54.5	13.6	92	51,000	6	<1
B 1	Soil	surface		7.9	25	218	221	50.0	9.9	72	7,370	9	2
2	Debris	1.2	4	7.0	50	462	524	49.4	12.6	121	580	15	15
3	Debris	1.5	5	8.2	25	448	111	21.4	11.7	126	25,000	11	1
C 1	Debris	0.3	1	12.7	30	98	1295	24.2	9.7	20	3,000	4	<1
2	Debris	1.5	5	10.5	25	132	120	16.3	11.7	10	3,000	6	1
3	Debris	3.0	10	11.0	25	194	1381	34.4	13.4	11	6,600	9	<1
D 1	Soil	0.6	2	6.5	15	154	441	9.2	9.0	4	35	<1	<1
2	Soil	1.2	4	5.6	35	103	345	15.8	13.5	9	27	<1	<1
3	Soil	1.5	5	6.6	14	490	537	21.4	13.7	9	700	11	6

Samples taken April 21, 1976.

TABLE 21 (continued)

Well/ Sample No.		Type of Sample	Depth of Sample		Parameter				
					Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
			m	ft			Paraffin	Aromatic	Polar
A	1	Debris	1.3	4.5	6.84	6.80	40.1	25.2	34.2
	2	Debris	3	11	26.40	21.40	42.3	5.6	52.0
B	1	Soil	Surface		5.54	5.50	41.9	28.6	29.4
	2	Debris	1.2	4	22.10	19.90	42.9	22.0	34.9
	3	Debris	1.5	5	13.40	13.10	44.0	27.1	28.8
C	1	Debris	0.3	1	0.21	0.17	29.2	15.4	55.2
	2	Debris	1.5	5	1.98	1.94	25.1	13.0	61.7
	3	Debris	3.0	10	0.69	0.58	38.8	28.5	32.6
D	1	Soil	0.6	2	0.05	0.03	32.5	22.3	45.1
	2	Soil	1.2	4	0.06	0.05	26.0	5.6	68.2
	3	Soil	1.5	5	0.55	0.52	39.2	21.3	39.2

TABLE 22. RESULTS OF WATER SAMPLE ANALYSES FROM WELLS 4, 9, 10, AND 11 CASE STUDY SITE D - CRANSTON, RHODE ISLAND

Well No.	Depth to Water Surface*		Parameter				
			Total Extractable Hydrocarbons mg/1	Oil Content mg/1	Oil Fractions, percent		
	m	ft			Paraffin	Aromatic	Polar
4	3.7	12.1	6.38	4.86	15.2	6.1	78.6
9	3.6	12.0	7.30	7.26	14.2	6.8	78.9
10	4.4	14.5	13.70	11.25	11.1	3.2	85.6
11	4.5	15	5.08	4.16	25.1	10.1	64.3

Samples taken April 21, 1976.

*Measured from top of casing to water surface background. Also, it appears that the oil detected in Wells 4, 9, and 10 is of a different composition than that found in Well 11, judging from the significant different fractions of paraffinic, aromatic, and polar hydrocarbons tested.

It is possible that the oil found in all EPA wells is from a source other than the debris disposal site. The area is used for vehicle maintenance; and thus, oil dumping on the porous soils would not be uncommon. The relative oil fractions for all well waters (Table 20) are significantly different than those found in debris samples (Table 19). Also, it appears that the three wells indicating oil contamination are not directly downstream from the disposal site. However, the local groundwater may change flow direction in response to seasonal changes during the year, so these wells could be picking up contamination from the debris area.

Conclusions and Recommendations for Further Studies--

The data suggests some lateral migration of oil from the disposal area may have occurred, but given the industrialized nature of the area, it is likely that the oil detected in offsite wells is from other sources. Overall, it appears that the fine-grained soil is adequately containing the debris-entrained oil.

EPA should continue to monitor the existing wells annually. Water samples obtained should be analyzed for oil content in addition to the existing parameters. There appears to be no need for further studies unless the EPA monitoring program begins to detect an increased oil content in the underlying groundwater.

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APPENDIX A

GUIDELINES FOR FIELD SAMPLING - "PROCEDURES FOR DISPOSAL OF OIL SPILL CLEANUP DEBRIS"

OBJECTIVES OF SAMPLING

Obtain data at case study sites where oil spill debris and oily wastes have been deposited. Data will be used to verify the environmental safety of methods to be recommended in a "how-to" disposal manual.

SAMPLES TO BE OBTAINED

In general, the following types of samples will be taken at each case study site:

- Oily material, from the surface at landspreading sites and from underground locations at landfilling sites
- Soil
- Groundwater

Specific locations, depths, and numbers of each type sample to be taken will be delineated in the monitoring plan for each case study site. At sites requiring subsurface sampling, a local driller with sampling capabilities must be retained.

MATERIALS

Table A-1 lists the basic materials and equipment necessary to obtain, preserve, and ship samples. Also, sufficient materials should be taken to record field sampling activities.

SAMPLING PROCEDURES

The following instructions are intended to guide field personnel in obtaining representative, uncontaminated samples of oily material, soils, and groundwater. However, all conditions cannot be anticipated so field personnel must exercise judgement in all sampling work.

TABLE A-1

MATERIALS REQUIRED FOR FIELD SAMPLING

Oil and Soil Samples

1. Small and large plastic bags such as "Whirl-Pac" and trash bags. (See field monitoring plan for specific number at each site.) Sufficient bag ties should also be available.
2. Well log forms
3. Shelby permeability tubes (driller may provide these)
4. Rubber gloves
5. Label tags
6. Waterproof marking pens
7. Knife and trowel for sample trimming
8. Hacksaw

Groundwater Samples

1. Two-liter glass bottles and lids for storing and shipping samples. These should be cleaned prior to arrival at case study site.
2. One-half liter sampling bottles
3. Water sampling device
4. Distilled water

Sample Shipment

1. Corrugated boxes with styrofoam liners; sufficient number to contain all samples to be gathered.

Sample Shipment (continued)

2. "Blue ice" or equivalent (These should be frozen prior to use to ensure cold sample temperatures are maintained during shipment.)
3. Tape, such as fiber packing tape
4. Shipping labels
5. Cord (optional)

Other Materials

1. Camera and color slide film
2. Clipboard and pen to record field notes
3. Map of case study site area

Oily Material and Soil Samples

Samples of the oily material and soils will be taken by (1) core sampling during drilling, and (2) by obtaining surface grab samples (applicable at landspreading sites only).

1. Core samples will be taken at various depths (specified in the monitoring plan) by a core sampler such as a Shelby corer. As soon as the sample has been removed from the corer, it must be placed in double plastic bags to seal the sample. Without prompt sealing of the sample, the core could dry and affect analytical results. The site name, depth of sample, and other pertinent information should be noted on a tag and included with the sample. For example, the following information should be included with each soil and oily material sample:

    - Project number
    - Date sampled
    - Site location
    - Sampler's initials
    - Depth of sample
    - Length of sample core
    - Well identification number tied to notation on map

2. A surface grab sample will be taken from each landspreading case study site. The sample should be obtained from a representative section of the area. Landspreading does not necessarily distribute or mix oil with soil evenly. Hence, there may be large clumps of oil in one area and relatively unoiled particles of soil in another. Try to obtain surface grab samples from an "average" area, not from one of the extremes.

    A topsoil sample not more than 4 in deep should be taken and placed in a plastic trash bag. This sample should then be double packed, tied, and labeled appropriately.

Well Logs

During well drilling, the field engineer should record a soil boring log. (See attached form, Figure A-1, as an example.) Each time the soil characteristics change, the depth should be noted on the log sheet along with color, moisture, texture, and the appearance of oil, if any.

Rely on the driller to assist in classifying the soils since he is usually familiar with local geology. Color photographs of the soil as it has been augered from the well may also be useful for later reference.

Water samples are to be obtained only when boring to depths indicated in each monitoring plan intercept groundwater. (It is thus possible that groundwater samples will not be taken at all sites.)

Groundwater Samples

Groundwater samples are to be collected using the standard sampling device. Water collected in the device is emptied into pre-cleaned 2-liter glass storage and shipping containers.*

The sampling device facilitates sampling in small diameter wells and must be kept clean at all times. It must not be allowed to rest on dirt or become contaminated with tap water. If there is any doubt as to possible contamination, the sampling device should be thoroughly rinsed with tap water and then rinsed with distilled water.

Groundwater samples will be obtained by lowering the sampling device down the well. After the sampling bottle has reached the bottom of the well and allowed to fill with water, it is pulled back to the surface and emptied into a 2-liter plastic container. This procedure is repeated until the 2-liter bottle is filled. After each well is sampled, it is important that the 1/2-liter sampling bottle be replaced prior to sampling another well in order to prevent cross contamination. Also, the sampler should be rinsed with distilled water between samplings.

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*Sample storage and shipping bottles are to be prepared as follows: Rinse bottles thoroughly with hot tap water, allow to cool, rinse with 1:1 HCl (reagent grade), cold tap water, and finally with doubly-distilled de-ionized water. Secure caps onto bottles to prevent any future contamination and prepare for shipment to the desired site. Note that no detergents of any type are to be used because of their phosphorous content.

TEST HOLE NO.______

DEPTH (FEET)	MATERIAL	DESCRIPTION	COMMENT

FIGURE A-1

All groundwater sample containers should be marked with waterproof marking pen to show the site name, well location, depth to groundwater, and date. Other pertinent data should be recorded in the field notes.

SAMPLE PACKING AND SHIPPING

All samples will be sent to SCS Long Beach as soon as practical after collection, chilling, and packing for shipment. Soil and oily material samples should be wrapped in at least two layers of paper to provide insulation to prevent containers from rubbing holes in other containers. "Blue ice" or equivalent should be included along with the groundwater samples to keep them at about 4°C. Water samples should also be wrapped in paper to prevent the sample codes from rubbing off.

All sample fractions should be packed in corrugated cartons lined with styrofoam to provide insulation and rigidity. If the transport time between the field and the laboratory is expected to be more than two days, enough blue ice should be used to keep the samples adequately chilled. Dry ice should not be used for shipping purposes. The carton(s) should be sealed with strong tape. Use of cord will facilitate carton handling.

Samples should be shipped via a reliable service. The mailing address must be clearly marked on each carton. Each carton should be insured.

APPENDIX B

METHODOLOGY FOR ANALYZING HIGH MOLECULAR WEIGHT HYDROCARBONS

A. EXTRACTION OF SEDIMENT SAMPLES

The recommended minimum sample weight is 100g. This amount can be increased for sediments found to be very low in extractable organics. Every fifth sample will be spiked with a 0.1μg hydrocarbon standard/g sediment using an appropriate n-alkane or isoalkane standard and a polycyclic aromatic standard which falls outside of the spectra of the compounds being measured. The water is double distilled and percolated through XAD-2 or Chromosorb-102 resin to remove trace organics. It should be stored in either glass or teflon containers. Excess water will be removed under vacuum. The filtrate is then extracted three (3) times with 25 ml of n-heptane. N-hexane and n-pentane can be substituted for n-heptane in all applications. The extracts are then combined and saved for later addition to the sediment extract.

The sediment sample is then vacuum-dried. Remove sample when dry. Contamination occurs during prolonged pumping on a dry sample. A complete column gas chromatographic analysis of the more volatile components of the vacuum pump oil should be performed to aid in the detection of contamination. This procedure serves to minimize sample manipulation. The vacuum-dried sediment is then extracted by the Soxhlet technique.

1. The Soxhlet Extraction

The vacuum-dried sediment is placed in a Soxhlet thimble, and extraction is allowed to proceed for 100 hours, or 300 turnovers, with one solvent change after twenty-four hours. The Soxhlet thimbles are thoroughly extracted for 72 hours using the toluene and weighed prior to addition of sample. If possible, glass fiber thimbles should be used. The solvent system to be used is a toluene:methanol (3:7) azeotrope. The extracts obtained from the sediment extraction and water washing are then combined and reduced in volume using a rotary evaporator. The dry weight of the extracted sediments is determined while in the thimble.

2. Sulfur Determination

The presence of elemental sulfur is determined by dipping activated copper wire into the extract. If the wire becomes immediately coated, the presence of sulfur is indicated. The sulfur should be removed by charging the extract onto an activated copper column. It is then eluted with three column volumes of toluene. The solvent is again reduced in volume with a rotary evaporator. It is then saponified in accordance with the procedure described in paragraph D. The sample is transferred to a tared vial, the remaining solvent removed with pre-purified N_2 and weighed on an analytical balance sensitive to 0.1 mg. The sample is then dissolved in a small volume of n-heptane for column chromatographic analysis.

B. EXTRACTION OF WATER COLUMN SUSPENDED PARTICULATES

Filters containing the particulate hydrocarbon samples shall be thawed, and tar balls and other extraneous material picked out under a dissecting scope. The filter and sample should then be dried. The filter and material shall then be refluxed with 50 ml of n-heptane for one hour. The extract shall be decanted and replaced with 50 ml of $CHCl_3$ and refluxed for an additional hour. The extracts will be combined and taken to near dryness on a rotary evaporator. A gentle stream of pre-purified nitrogen will be used to remove the remainder of the solvent. The weight of lipid material will be determined by either using an analytical balance accurate to 0.1 mg or the method described in paragraph E for weight determination of column chromatographic fractions.

Following a weight determination, the sample will be dissolved in n-heptane and fractionated as described in the column chromatography section.

C. EXTRACTION OF WATER COLUMN FILTRATES

The filtered water sample will be acidified to a pH of 2 with hydrochloric acid and extracted with $CHCl_3$. The extraction efficiency will be demonstrated prior to any analyses being accomplished and shall be greater than 95 percent for aliphatic and aromatic compounds. The $CHCl_3$ extract shall then be reduced in volume on a rotary evaporator and then taken to dryness with a gentle stream of pre-purified N_2. The lipid residue will be weighed and then re-dissolved in n-heptane for column chromatography.

D. SAPONIFICATION

All samples requiring saponification will be handled as described below. Saponification will be carried out by refluxing the sample with 0.5 N KOH in methanol:water. This mixture will be refluxed either under pre-purified nitrogen or with a filter of molecular sieve or silica gel to prevent contamination from external hydrocarbons in the laboratory. The saponification reaction shall be continued for at least four hours.

Upon completion of the saponification, the mixture shall be diluted with an equal volume of saturated NaCl solution. If no emulsion exists, the toluene layer should be decanted, followed by three extractions of the aqueous mixture with n-heptane. The volume of n-heptane used for each extraction should be equivalent to the volume of toluene initially used in the saponification. The toluene and n-heptane fractions are then combined and reduced in volume with a rotary evaporator.

If an emulsion exists, the entire mixture should be extracted three times with the n-heptane. The extracts obtained should be placed in glass centrifuge tubes with teflon-lined caps and then spun down so that the phases can be easily separated. A refrigerated centrifuge may aid separation. The organic phases will then be combined and back extracted with an equal volume of saturated sodium chloride solution. The saturated sodium chloride solution will then be re-extracted once with n-heptane, and all the organic phases will be combined. The organic solvents will then be reduced in volume on a rotary evaporator.

E. COLUMN CHROMATOGRAPHY (L.C.)

All sample types will be chromatographed in the manner described below. A weight ratio of about one-hundred (100) parts alumina to one (1) part lipid sample and two-hundred (200) parts silica gel to one (1) part lipid sample will be used. The column should have a length to i.d. ratio of 20:1. Both the silica gel and the neutral alumina will be Activity I. The columns will be prepared by first suspending the absorbents in n-heptane and then pouring a slurry of silica in n-heptane into a standing column of n-heptane and allowing it to settle. This will be followed by pouring the alumina slurry into the column. The column should then be rinsed with two column volumes of n-heptane. At no time should the column be allowed to run dry. The weighed extract will then be applied to the column in a small volume of n-heptane and the aliphatic fraction eluted with two column volumes of n-heptane. This will be followed by elution of aromatics with two column volumes of benzene. The eluates from the two fractions will then be taken to near dryness on a rotary evaporator. They will then be transferred to screw cap vials with either aluminum or teflon lined caps, and the remainder of the solvent removed with a light stream of pre-purified nitrogen.

Add a small measured volume of a suitable solvent to the residue, and, using a one (1) 1 syringe, place a one (1) 1 aliquot on the weighing pan of a microbalance. An alternative method is the use of tared vials and determination of weight difference using an analytical balance. After the solvent evaporates and the balance has come to equilibrium, usually one to two minutes, the residue can be weighed. The weight of the total residue can then be determined by extrapolation. This method helps in avoiding problems associated with the presence of salts, and sulfur in the vial which may not have been completely removed. Additionally, an appropriate sample volume for injection into the gas chromatograph can be determined in this manner. Appropriateness of sample volume is a function of gas chromatographic operating conditions and the composition of the sample itself.

F. GAS CHROMATOGRAPHY (GC)

Each eluted fraction obtained from the column chromatographic separation will be re-dissolved quantitatively in a small volume of n-heptane, and aliquots will be withdrawn and weighed on a microbalance to determine appropriate volumes for injection on the gas chromatograph. Stainless steel or glass capillary columns coated with Apiezon L, OV-101, DEGG, or SE-30 should be used for the analysis. The columns should be high resolution with at least 50,000 theoretical plates. The gas chromatograph will be capable of linear temperature programming and will be operated with a hydrogen flame detector with a sensitivity of at least 5×10^{-11} gms/sec for n-decane at a signal of noise ratio of 5:1. Retention indices will be computed based on known standards.

The gas chromatographic analysis should allow for isolation and characterization of the following: normal, branched, and isoprenoid alkanes from C_{14} to at least C_{32}; condensed and non-condensed cycloalkanes (in a cursory way, if present); and homologous series of alkyl benzenes and alkyl-substituted polycyclic aromatics such as chrysene with retention times up to n-C_{32}.

For the analyses of samples during this current contract, both a Hewlitt-Packard 5730A and an ANTEK 300 fitted with 50' SCOT OV101 columns were used. Starting temperature was 120°C for 2 minutes followed by temperature programming at 1.6°C/min to 270°C with a final hold for 32 min. Output from the FID detector was fed into a strip recorder (for visual observation) and simultaneously onto magnetic tape through an analog audio-frequency convertor. Playback of the magnetic tape was accomplished by utilizing a 4-8 fold increase in speed and output on a recorder through a computer-integrator.

G. OTHER ANALYTICAL METHODS

Total Solids (Moisture) - evaporation to dryness @ 103-105°C as per Section 208A, p. 91 in Std. Methods for the Examination of Water and Wastewater, 14th Edition, 1975.

Fixed Nitrogen - phosphate (pH7) buffer added and NH_3 distilled off to atmosphere. Kjeldahl digestion followed on residue as per Section 421, p. 437, Std. Methods 14th Edition, 1975.

Organic Acids - separation through silicic acid column followed by titration with standard NaOH as per Section 504, p. 527, Std. Methods 14th Edition, 1975.

Phosphates - colorimetric method using ascorbic acid as per Section 425F, p. 481, Std. Methods 14th Edition, 1975.

Chlorides - titration with mercuric nitrate as per Section 408B, p. 304, Std. Methods 14th Edition, 1975.

Lead, Nickel, Iron - atomic absorption as per EPA Methods for Chemical Analysis of Water and Wastes, 1974, pages 112, 141, 110.

Mercury - flameless atomic absorption as per EPA Methods for Chemical Analysis of Water and Wastes, 1974, p. 134.

Biological Activity - total aerobes, total anaerobes, and yeast and molds were done by standard bacteriological techniques, as outlined in Std. Methods 14th Edition, 1975, pages 904-1004.